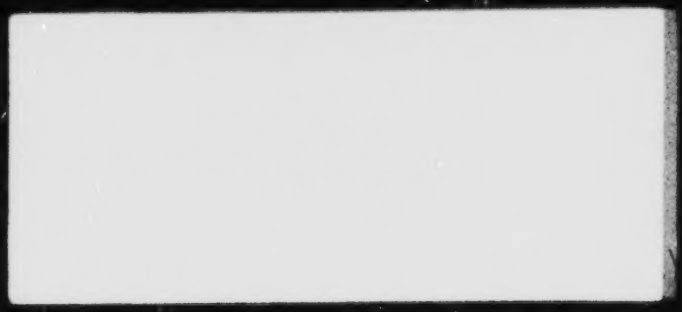
Final Report



A project under the Canada
New Brunswick Conservation
and Renewable Energy
Demonstration Program

rpc

research and productivity council
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40

COMBUSTION TEST FACILITY PROGRAM

RESEARCH & PRODUCTIVITY COUNCIL

FREDERICTON, N.B.

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Canada/New Brunswick Conservation and Renewable Energy Demonstration Program

The Conservation and Renewable Energy Demonstration Program Program is administered in New Brunswick by the Energy Secretariat and managed jointly with Energy, Mines and Resources Canada. The Program is designed to help demonstrate promising conservation and renewable energy technologies, to develop public awareness and understanding of these technologies, and to create employment in new or existing industries.

Through over 100 demonstration projects in New Brunswick, a wide variety of conservation and renewable energy technologies have proven to be technically sound and economically attractive. These demonstration projects should now provide a catalyst for commercialization and lead to widespread adoption of many of these proven technologies.

This final report is based on a project which was financially supported by the Energy Demonstration Program. For further information on other demonstration projects funded in New Brunswick under this program, contact:

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Le Programme de démonstration des économies d'énergie et des énergies renouvelables est administré au Nouveau-Brunswick par le Secrétariat à l'énergie, en collaboration avec Energie, Mines et Ressources Canada. Ce programme tente d'abord de vérifier la fiabilité des techniques de conservation d'énergie, d'accroître la sensibilité du public envers ces techniques et, enfin, de favoriser la création d'emplois au sein des industries nouvelles ou déjà existantes.

Un grand nombre de projets de démonstration se sont avérés à la fois techniquement réalisables et économiquement attrayants.

Le succès ainsi rencontré encourage la commercialisation des procédés les plus accessibles. Cela entraînerait certes l'adoption d'un grand nombre de ces techniques par les propriétaires de domiciles et par l'industrie privée.

Ce rapport final est basé sur un projet qui a reçu une aide financière du Programme de démonstration. Pour de plus amples renseignements, communiquez avec la:

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D I S C L A I M E R

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TABLE OF CONTENTS

		PAGE
1.0	EXECUTIVE SUMMARY	1
2.0	INTRODUCTION	2
	PART I - TEST FACILITY	
3.0	ESTABLISHMENT OF THE TEST FACILITY	3
4.0	SERVICES RENDERED	5
	4.1 Commercial Bake Oven	5
	4.2 Oil Tank Removal	5
	4.3 Friction Furnace	5
5.0	FURNACE EFFICIENCY SURVEY	6
6.0	PRELIMINARY WORK	7
	6.1 Laboratory Furnace Efficiency Determinations	7
	6.2 Comparison of Combustion Test Equipment	7
	PART II - OIL FURNACE TEST PROGRAM	9
7.0	BACKGROUND TO OIL FURNACE TEST PROGRAM	10
	7.1 Summary	10
	7.2 Introduction	10
	7.3 Background	11
8.0	LABORATORY PROGRAM	14
	8.1 Test Method	14
	8.2 Test Furnaces	14
	8.3 Test Equipment	14
	8.4 Results	15
	8.4.1 Variation of Nozzle Capacity	15
	8.4.2 Variation of Nozzle Spray Angle	15
	8.4.3 Variation of Nozzle Spray Pattern	16
	8.4.4 Flame Rentention Head	16
	8.4.5 Installation of Ceramic Felt Chamber Liner	16
	8.4.6 Delayed Action Solenoid Valve	17
	8.4.7 Variation of Pump Pressure	17
9.0	FIELD TEST PROGRAM	18
	9.1 Background	18
	9.2 Retrofit Measures	18
	9.3 Results	20
	9.4 Cost vs. Benefit	21
10.0	CONCLUSIONS	22

		PAGE
11.0	RECOMMENDATIONS	22
	PART III - WOOD FURNACE TEST PROGRAM	25
12.0	BACKGROUND TO WOOD RESIDUE COMBUSTION EQUIPMENT TEST PROGRAM	26
13.0	TEST PROGRAM	29
	13.1 Background	29
	13.2 Test Equipment and Procedure	30
	13.3 Choice of Residues	31
14.0	GRAVITY FED CHIP/SAWDUST BURNER	32
	14.1 Description	32
	14.2 Test Parameter Variations	32
	14.3 Test Procedure	33
	14.4 Results	33
	14.4.1 Feed Properties	33
	14.4.2 Combustion	34
	14.4.3 Efficiency of Combustion/Heat Output	34
	14.4.4 Effects of Moisture Content	35
	14.4.4.1 Feed Properties/Combustion	35
	14.4.4.2 Efficiency/Output	35
	14.4.4.3 CO/HC Emissions	36
	14.4.5 Mechanical Design/Safety Considerations	37
	14.5 Conclusions	38
15.0	AUTOMATIC STOKER SYSTEM	39
	15.1 Description	39
	15.2 Test Parameter Variation	40
	15.3 Test Procedure	40
	15.4 Results	41
	15.4.1 Feed Properties	41
	15.4.2 Combustion	42
	15.4.3 Efficiency of Combustion/Heat Output	42
	15.4.4 Effects of Moisture Content	43
	15.4.4.1 Feed Properties/Combustion	43
	15.4.4.2 Efficiency/Output	43
	15.4.4.3 CO/HC Emissions	44
	15.4.4.4 Mechanical Design/Safety Considerations	44
	15.4.5 Conclusions	45
16.0	RECOMMENDATIONS	47
	PART IV - INFORMATION TRANSFER	48
17.0	INFORMATION TRANSFER	49

	PAGE
APPENDIX A - Oil Furnace Test Program	52
Oil Efficiency Calculation	53
Table A-1 - Equipment List	56
Figure A-1 - Test Schematic	57
Table A-2 - Guide to Nozzle Specifications	58
Table A-3 - Oil Furnace Test Results	59
Table A-4 - Efficiency by Nozzle Capacity	60
Table A-5 - Test Results - McClary Furnace	61
Table A-6 - Efficiency by Spray Angle	62
Table A-7 - Efficiency by Spray Pattern	63
Table A-8 - Improvement Due to Retention Head	64
Table A-9 - Efficiency Imrpovement Due to Liners	65
Table A-10 - Pressure Variation	66
Figure A-2 - Combustion Facility Photograph	67
APPENDIX B - Residential Retrofit	68
Table B-1 - Residential Test Furnace Specifications	69
Table B-2 - Retrofit Measures	70
Table B-3 - Results of Cleaning and Retrofits	71
Table B-4 - Cost-Benefit Analysis	72
Table B-5 - Case III Adjusted Figures	72
Figure B-1 - Efficiency Vs. Time Graphs: Furnace I	73
Figure B-2 II	74
Figure B-3 III	75
Figure B-4 IV	76
APPENDIX C - Wood Residue Test Program - Background Data	77
Table C-1 - Wood Residues	78
Table C-2 - Physical Dimensions of Fuel	79
Table C-3 - Equipment List	80
Figure C-1 - Photograph of Residues	81
Figure C-2 - Test Schematic	82
APPENDIX D - Gravity Fed Burner	83
Table D-1 - Gravity Fed Burner Test Results	84
Table D-2 - Moisture vs. Efficiency	89
Table D-3 - Moisture vs. CO/HC Emissions	89
Figure D-1 - Graph of Moisture vs. Efficiency	90
Figure D-2 - Photograph	91
Figure D-3 - Burner Schematic	92

	PAGE
APPENDIX E - Auger Fed Stoker	93
Table E-1 - Auger Fed Stoker Test Results	94
Table E-2 - Combustion Air Settings vs. Efficiency	100
Table E-3 - Efficiency/Output vs. Moisture Content	101
Table E-4 - CO/HC Emissions vs Moisture Content	101
Figure E-1 - Graph of Moisture vs. Efficiency	102
Figure E-2 - Auger Fed Stoker Schematic	103
Figure E-3 - Photographs	104

1.0 EXECUTIVE SUMMARY

The objective of this demonstration was to investigate the energy efficiencies of currently utilized or available domestic heating equipment whether they be of the oil, gas or wood-burning varieties. This included not only an evaluation of new/energy efficient designs but also concerned investigation into the potential for upgrading the older oil-fired system.

It has been demonstrated that it is possible to raise the steady state efficiency of an oil-fired appliance to roughly 80% by the application of certain devices and techniques. Specifically, a group of four residential furnaces was upgraded from an average of 69.5% to a level of 78.9%. In each case fuel consumption was decreased, yielding an average simple payback period of 1.95 years on the retrofit.

Similarly, it has been shown that efficiencies (steady state) of 80% or better are also attainable when combusting wood residue. Selection of the proper size, shape and moisture of the particulate wood fuels for the burner is the key to success. The products of incomplete combustion have been found to be reduced (by as much as 4-5 times), from the levels encountered when burning stick wood.

In order to disseminate the gathered information (specifically on oil furnace efficiency improvement) evening seminars were held for the general public. Their success indicated that such a program should be continued.

A second retrofit project for oil-fired furnaces is recommended, not only to evaluate newly available conservation devices, but also to further increase people's awareness of the value of furnace upgrading.

Similarly, extension of the development of wood particulate fuel combustors will aid with their adoption by the public. Development should focus on fuel quality and combustion technology. Testing for certification purposes will also be important.

SOMMAIRE-RECOMMANDATION

Le but de cette démonstration était de vérifier le rendement énergétique des appareils de chauffage domestique actuellement utilisés ou sur le marché, qu'ils soient au gaz, au mazout ou au bois. Cette étude consistait non seulement à évaluer les nouveaux dispositifs à haut rendement énergétique, mais également à verifier ler possibilitées d'amélioration des anciens appareils au mazout.

Il a été démontré qu'il est possible d'augmenter le rendement du régime permanent d'un appareil de chauffage au mazout à environ 80 % en faisant appel à divers dispositifs et à certaines techniques. En fait, un groupe de quatre fournaises résidentielles virent leur rendement passer d'environ 69,5 % à 78,9 %. Dans chacun des cas, la consommation de combustibie a baissé, pour un recouvrement moyen de 1,95 an des dépenses de rattrapage.

De même, il a été prouvé qu'il était possible d'obtenir un rendement (du régime permanent) de 80 % ou plus en brûlant des résidus forestiers. La clé du succès dans ce cas repose sur le choix des particules de bois, en prenant soin qu'elles aient la grosseur, ainsi que la forme et le degré d'humité appropriés. Les produits de la combustion incomplète sont plutôt réduits (de4 à 5 fois) par rapport à la grosseur où on les retrouve lorsqu'on consume des bouts de bois.

Afin de répandre l'information recueillie (particulièrement sur le rendement amélioré des fournaises au mazout), des soirées d'information se sont tenues pour le public en général. Le succès de ces soirées indique clairement qu'il faudrait poursuivre ce programme.

Un second projet de rattrapage des fournaises au mazout est recommandé, non seulement pour évaluer les nouveaux dispositifs d'économie de l'énergie, mais également pour mieux sensibiliser la population au fait qu'il vaut la peine d'améliorer les fournaises.

En outre, la poursuite du perfectionnement des appareils de combustion de particules de bois favorisera leur adoption par le public. Les aspects visés devraient être la qualité du combustible et les techniques de combustion. Il serait néanmoins important de s'occuper également des essais et de l'approbation des appareils.

PART I

Test Facility

2.0 INTRODUCTION

As a result of the numerous inquiries received at the Research and Productivity Council (RPC) over the years, dealing specifically with combustion related matters, it was felt that the establishment of a combustion centre would be a logical approach to meeting this and future demand. These questions, more often than not from the residential sector, have ranged from the retrofitting of oil furnaces to the proper operation of a wood stove. It was this that encouraged the establishment of such a facility. The Combustion Demonstration and Test Facility (CDTF), established under the auspices of the Canada-New Brunswick Conservation and Renewable Energy Demonstration Agreement, was funded jointly by the Federal/Provincial governments and RPC. The sum allocated to this project was $400,000, 25% of which was contributed by the Research and Productivity Council.

The scope of activities to be undertaken by the CDTF were as follows:

1. To establish the facility.

2. To evaluate the efficiency of some existing residential heating systems in this province (primarily oil-fired).

3. To evaluate oil furnace retrofit devices and techniques in the laboratory.

4. To demonstrate several economic oil furnace retrofits in domestic situations.

5. To evaluate new and/or energy efficient heating systems, including locally manufactured wood residue burners.

6. Conduct or have conducted, courses, seminars and tours for interested individuals or groups.

7. Provide a testing service, for a fee, to owners, distributors, or manufacturers of heating equipment.

3.0 ESTABLISHMENT OF THE TEST FACILITY

Prior to performing any work it was first necessary to establish a combustion laboratory. In order to comply with the terms of the agreement and also to avoid a duplication of on-going activities at other facilities in the country a number of information visits were made. These included the Canadian Combustion Research Laboratory (Ottawa), the Canadian Standards Association (Rexdale), Ontario Hydro (Niagara Falls) and the Energy Test and Information Centre (Technical University of Nova Scotia, Halifax). In addition a number of local manufacturers of heating appliances were contacted in order to acquaint them with the facility and to determine whether or not it could be of benefit to them. The response was very favourable in all quarters and as a result a clearer understanding of what was needed evolved.

As demonstration was expected to be a significant aspect of this project, it became necessary to assemble a collection of common and not-so-common home heating equipment, of the oil, gas and wood-fired varieties. After much investigation, which yielded a long list of possibilities, the following selection was eventually made:

Oil-Fired

Esso Aqua Thermic (hydronic)
Esso Econo Blue (hot-air)
McClary-Easy (hot-air)
Irving (Fawcett hot-air)

Gas-Fired

Smart's Chinook (hot-air)
Arkla Recuperature (hot-air)
A.O. Smith (hydronic)
GSW McClary (hot water heater)

Wood-Fired

Lakewood Cottager (wood stove)
Sawdust burner (gravity fed)
Automatic stoker (auger fed)

These appliances represented not only the most common of units but also those of a more modern energy efficient design. This latter category would include the Esso Econo Blue and the Arkla Recuperative condensing flue gas furnace. As well, the automatic wood residue stoker system could be mentioned here as a more controlled approach to the burning of wood than that currently employed with a log wood stove. A photograph of the facility is given as Figure A-2.

At this point it was necessary to assemble the test equipment and miscellaneous hardware. This included a series of gas analyzers, digital weight scales, a programmable data logger, computer, oil and propane flow meters, air velocity meter, portable combustion test equipment as well as a host of other items. A complete list may be found in Table A-1.

Initially it was thought that the bulk of the work would center around the oil-fired system as it is undoubtedly the most prevalent in the province. Following this, an examination of current gas burning equipment would be undertaken, in anticipation of the eventual arrival of a natural gas pipeline. To conclude, a study of some representative wood burning equipment would be made.

After devoting a great deal of time to the study of oil furnace retrofit devices and then initiating the field test program it was decided, after much discussion with all concerned parties, to essentially by-pass (for the present time) examination of the gas-fired units. It was felt that funds could be more usefully spent investigating the many unanswered questions dealing with wood residue combustors.

Finally, preparations were begun to disseminate the acquired information in the form of workshops, seminars and the like.

It should be mentioned here that during the set-up period a number of requests for assistance were received and acted upon by the combustion group. These will be discussed in more detail in Section 4.0.

4.0 SERVICES RENDERED

4.1 Commercial Bake Oven

RPC was approached by a local restaurant owner to evaluate a propane fired commercial bake oven recently purchased from the U.S. which did not bear the approval of the Canadian Gas Association (CGA). Discussions were held with the Gas Inspection Branch of New Brunswick's Department of Labour and the appropriate CGA standard obtained. The unit was tested in compliance with the standard, the results were reported to the Department of Labour and the unit was accepted by the authorities as meeting the standard. These steps ultimately saved the owner much time and expense.

4.2 Oil Tank Removal

Oil storage tanks were required for the facility and advantage was taken of private citizens conversion from oil to electric heating (assisted by grants from the Canadian Oil Substitution Program). Two oil tanks were pumped out, removed from the residences, installed at RPC and re-filled.

4.3 Friction Furnace

A Campbellton based entrepreneur submitted to RPC a water-cooled friction furnace which he had designed and built himself. He was interested in having its efficiency measured.

This device consisted essentially of a steel drum-within-a-drum design, between which was a layer of oil. Rotation of the inner drum by an electric motor created heat which was transferred to a quantity of water surrounding the outer drum.

Extensive testing was undertaken to determine both energy input and energy output so as to ultimately derive an operational efficiency. Details of this work were reported to the client in RPC Report No. E/83/83, dated 1983-06-28.

5.0 SURVEY OF FURNACE EFFICIENCIES

In the press release issued at the inception of this project, it was indicated that RPC was in a position to provide a residential oil furnace efficiency test service to the general public. It was hoped that a sufficient number of requests would be received to provide a good sample. Unfortunately the response was poor and so the decision was made to make use of the results of a 1977 survey, conducted by the Conservation Council of New Brunswick, of 690 oil furnaces in the Fredericton area. It was felt that the average steady state efficiency of 72.4% obtained from this study could be viewed as representative of the general state of oil-fired furnaces throughout the province.

6.0 PRELIMINARY WORK

6.1 Efficiency Determinations

Once the laboratory had been readied for operation it was decided to demonstrate the value of the flue gas analyzers by utilizing them to determine the steady state efficiencies of the oil and gas fired appliances which had been acquired. A detailed description of the procedure involved may be found in Section 8 and a sample efficiency calculation in Appendix A. Note should be taken that any future reference to efficiency implies steady state efficiency unless otherwise indicated.

On this initial as-received basis with no adjustments made to the furnaces, the following results were obtained:

Unit	Fuel	Steady State Efficiency %
Esso Aqua Thermic	oil	80.8
Esso Econo Blue	oil	72.0
McClary-Easy	oil	72.3
Irving	oil	62.0
Smart's Chinook	propane	81.9
Arkla Recuperative	propane	72.0
A.O. Smith	propane	75.7
GSW McClary	propane	71.1

6.2 Comparison of Combustion Efficiency Test Equipment

Questions have frequently been raised as to whether or not the portable combustion test equipment used by furnace servicemen, boiler operators and the like is truly accurate. In order to evaluate this situation, a number of essentially simultaneous efficiency tests were performed using the Beckman Gas Analyzers (standard), a Bacharach Test Kit and a digital FEM (Fuel Efficiency Monitor). Comparative results may be viewed in the following table.

$\%O_2$			$\%CO_2$			Stack Temp °F			% Efficiency		
Bach	FEM	Beck	Bach	FEM	Beck	Bach	FEM	Beck	Bach	FEM	Beck
12	11.1	10.91	7 3/4	--	7.84	710	700	693	69¼	64.5	68.1
11¼	12.2	11.82	8 3/4	--	7.78	710	702	711	71 3/4	61.2	65.0
12	12.2	11.76	7 ½	--	7.78	710	706	736	68½	61.1	64.2
10	11.7	10.90	8 ¼	--	7.52	710	699	734	70½	62.9	66.7
12	11.6	11.01	7 3/4	--	7.57	710	704	733	69¼	63.0	66.4
11½	11.5	11.31	7 ½	--	7.51	710	701	713	68½	63.4	66.5
							Average		69½	62.7	66.2

If we take the Beckman results as the standard, we find the Bacharach kit to read roughly 3.3 points too high and the FEM 3.5 points too low. The fact that the calorific value of the fuel used in each case varies somewhat may account partially for this. Nevertheless both of these devices are relatively accurate and serve their purpose satisfactorily.

PART II

Oil Furnace Test Program

7.0 BACKGROUND TO OIL FURNACE TEST PROGRAM

7.1 Summary

Laboratory and field work both indicate that by application of the proper retrofit techniques, it is possible to raise the efficiency level of an existing oil-fired furnace by as much as 10-15%.

This may be an attractive alternative to the replacement of an older unit with a newer, more efficient one.

7.2 Introduction

A high percentage of the oil-fired furnaces presently in use do not perform at their peak efficiencies for one reason or another. Over-sized nozzles, mismatched oil spray patterns, poor oil/air mixing, high levels of excess air, soot accumulation and poor heat exchanger design are some of the major causes of this condition.

Furnace retrofitting, the installation of certain after-market devices, is the method by which this problem can be alleviated. Coupled with a good cleaning and the proper nozzle selection this process can substantially increase the steady state efficiency of a sub-standard furnace. Further, the heating requirements of the house will be more adequately matched. With this in mind a test program was devised to determine whether or not retrofitting could actually produce the results claimed and, if so, to what extent.

Testing was carried out on two levels; firstly, in the laboratory in order to ascertain the degree of efficiency improvement possible and, secondly, in the field in order to monitor performance under actual residential operating conditions.

7.3 Background

Prior to the installation of any retrofit device, it is imperative that the furnace first be properly cleaned and tuned-up. An important part of this procedure involves selection of the proper nozzle for the application in question as it is not necessarily the one suggested by the manufacturer.

There are three parameters which may be varied in order to properly match the nozzle type with the design of the combustion chamber and the capacity of the heat exchanger:

a) Capacity - rated in U.S. gallons per hour (USGPH)
b) Spray angle - in degrees
c) Spray pattern - typically hollow, solid or semi-solid

Note: Table A-2 gives a short guide to letter designations used by various nozzle manufacturers.

e.g. 0.85 80° H
a b c

Charts are of course available which indicate the proper angle and pattern to be used with a specific chamber and these are, to a certain extent, fixed. It is possible however, to decrease the nozzle capacity in order to reduce fuel consumption and improve operating efficiency. If the furnace runs less than 70% of the time on the coldest day of the year, downsizing of the nozzle is probably in order. This is especially applicable if the homeowner has installed supplemental heating at some point after initial installation of the furnace or reduced the demand for heat by increasing insulation or reducing infiltration.

In order to evaluate this situation, a series of nozzles ranging in capacity from 0.55 to 1.25 USGPH and with various spray angles and patterns were tested.

At this point, consideration can be given to retrofitting. Following is a brief description of the devices selected for examination. The choice was made on the basis of least cost and maximum purported performance.

Flame Retention Head

The flame retention head is a special end cone possessing a veined configuration and a smaller opening than a standard cone. When fitted over the blast tube this device imparts a superior swirl to the oil and air resulting in better mixing, improved combustion and ultimately a higher furnace efficiency.

Ceramic Felt Combustion Chamber Liner

The ceramic felt liner or "Wet-Pak" is a moist, flexible liner which is fitted inside the existing chamber. When the furnace is fired, the liner cures to a rigid form.

There are essentially three reasons for the use of this product. Firstly, if the nozzle is drastically downsized the dimensions of the combustion chamber must be reduced to retain compatibility. Secondly, a liner may be necessary as a protective measure against the higher temperatures encountered when downsizing or using a flame retention head. This is particularly important if the chamber is in direct contact with the primary heat exchanger or if the chamber is constructed of stainless steel or firebrick. These two materials are particularly susceptible to damage caused by high temperatures. Finally, if the combustion chamber is deteriorating a liner may be used to greatly extend its life.

Delayed Action Solenoid Valve

The delayed action solenoid valve is a device which fits into the oil line between the pump outlet and the nozzle and delays entry of the oil into the chamber for about 10 seconds until the pump and blower have reached their optimum operating conditions. Additionally, at the end of the cycle, the valve shuts off the oil supply just prior to cessation of ignition. This reduces substantially the production of smoke at start-up and shut-down of the system.

Other Devices (Not Tested)

1. Automatic Stack Damper

This device closes off the stack once the burner shuts off thereby preventing the escape of warm house air through the hot components of the furnace and up the chimney. When the burner starts again, the damper re-opens.

2. Heat Recovery

If stack temperatures are excessively high, a heat reclamation device may be installed in the flue pipe to extract this waste heat. These units are prone to sooting, however, and are only effective at temperatures in excess of 700°F.

3. Combustion Air Inlet Damper

This is a relatively new device on the market. It performs a function similar to that of the stack damper except it works on the burner air supply rather than in the stack.

None of these devices were employed in the four residential furnace retrofits for the following reasons:

a) Item 2 is not usually recommended for reasons given above.

b) It was felt that installation of 1 and/or 3 would cloud the benefits of the other retrofit devices to the point that comparison with laboratory results would become impossible.

8.0 LABORATORY PROGRAM

8.1 Test Method

Efficiency measurements were carried out using the stack heat loss method. This was accomplished by monitoring the flue gas temperature and the concentrations of its three major constituents (oxygen, carbon dioxide, carbon monoxide). Some 20-30 minutes of steady state data was recorded during each test. This data, coupled with a knowledge of the chemical makeup and the calorific value of the oil permitted efficiency determinations to be made. A sample calculation appears in Appendix A.

8.2 Test Furnaces

Two units were selected for this work, the first a well corroded 20 year old Irving (Fawcett manufactured by Enheat Ltd.) hot-air furnace and the second a 15 year old McClary Easy system, also hot air. This second unit was however involved in only one set of tests, those dealing with nozzle parameter variation.

8.3 Test Equipment

Gas analysis was performed with Beckman analyzers, the output of which was fed to a programmable Kaye data logger. The data logger produced an 8½" x 11" hard copy of the raw information recorded every 10 seconds and printed every minute, as well as an output which was transmitted to a Hewlett-Packard micro computer. At the operator's discretion the data could either be stored for later analysis or processed at the time, giving a calculated efficiency and a graphic display over the steady state period. Table A-1 lists the equipment involved while Figure A-1 shows the test set-up schematically.

8.4 Results

8.4.1 Variation of Nozzle Capacity

Irving Furnace

This unit contained a brick chamber 12" in diameter and 12" in depth. It was equipped with an Aero F-500 burner fitted with a 0.85 70°H nozzle. On this "as received" basis the furnace was found to be 62.0% efficient.

As previously mentioned, nozzle capacity was varied from 0.55 to 1.25 USGPH. Prior to each test the burner combustion air supply was adjusted to achieve a Bacharach-Shell smoke number of 1½ - 2.

From Table A-3 it is apparent that a maximum efficiency (77.3%)occurred with a 0.75 nozzle, although on average the best results were found between 1.00 and 1.25 (Table A-4, column 3). Literature [1,2] recommends a nozzle of 1.25 - 1.35 USGPH for this particular application.

McClary Furnace

This furnace, rated for a 0.75 80° solid nozzle, was fitted with a variety of nozzles and tested as before. Results may be found in Table A-5.

It will be noted that there is very little variation in efficiency regardless of the nozzle used. Generally speaking though, it can be concluded that a maximum efficiency (81.5%) was found at 0.65 USGPH.

8.4.2 Variation of Nozzle Spray Angle

In all cases when nozzles of similar capacity but differing spray angle (60° or 80°) were compared, those with the smaller angle performed more satisfactorily. Tables A-5 (McClary) and A-6 (Irving) give these results.

8.4.3 Variation of Nozzle Spray Pattern

From the tests conducted it can be seen that solid and hollow nozzles performed equally well with the former being more effective at low flows and the latter at higher ones. Generally speaking, semi-solids were found to be poor performers. Consult Tables A-5 (McClary - Column 5) and A-7 (Irving).

8.4.4 Flame Retention Head (Irving furnace only)

The test unit was equipped with an AFC 2 head rated for 0.65-1.10 USGPH. Again the entire series of nozzles was examined. The largest average improvement in efficiency, 8.3 points, was noted in the 1.00 gallon range. The average overall improvement was found to be 4.8 percentage points. Details may be found in Table A-8.

8.4.5 Installation of Ceramic Felt Chamber Liners (Irving)

In order to see whether or not nozzle size was truly dependent on chamber size a liner rated for 0.85 - 1.25 USGPH was placed inside the chamber and a series of nozzles tested. Following this, the liner was removed and one of smaller dimensions substituted (0.75 - 1.00). With liner 1, the peak efficiency occurred at 0.85 USGPH (75.0%) while with liner II it was 0.75 USGPH (76.9%). See Table A-4.

Installation of Liner I produced an average overall efficiency improvement of 0.0%, while Liner II gave a 2.3 point improvement. In both cases a sizable improvement was noted with the smaller nozzles while at the other extreme efficiencies actually declined. This obviously demonstrates the need for matching nozzle and chamber sizes. See Table A-9.

1. Field, Edwin M. "Oil Burners". Howard W. Sams and Co. Inc., 1970, pp. 87.
2. Delavan "Oil Burner Nozzles & Accessories for Residential and Industrial Applications", pp. 5.

8.4.6 Delayed Action Solenoid Valve (Irving)

Evaluation of this item was rather qualitative as it relied on simple observation only. An opening was cut through the side of the furnace and a glass panel installed in order that the interior of the chamber could be viewed during firing. The system was started up and shut down several times, both with and without the solenoid valve installed. The difference in performance was not obvious although it was quite evident that the production of smoke was decreased by this device.

8.4.7 Variation of Pump Pressure (Irving)

As a final set of tests it was decided to investigate the effect of pump pressure variation on the steady state efficiency. It was thought that increasing pressure would result in a finer oil spray entering the chamber thus improving combustion and therefore efficiency.

Table A-10 shows the results of these tests. It appears that pressure variation has little effect on steady state efficiency, although at 100 psi the numbers are marginally better than at the other settings. On average 100 psi produced an efficiency of 76.1% while the next best occurred at 80 and 120 psi (75.7%).

It should be noted that these results will not hold true for all furnace types. In particular, optimum nozzle specifications will vary depending on combustion chamber design. Nevertheless overall efficiency improvement of the magnitude indicated is possible with any unit that may be operating below the norm.

9.0 FIELD TEST PROGRAM

9.1 Background

As the laboratory tests had shown the benefit of retrofitting it was decided to modify a number of furnaces in residential situations and monitor them for steady state efficiency and fuel consumption over the 1983-1984 heating season. This was seen to be necessary in order to determine whether or not the laboratory results could be reproduced under actual domestic conditions.

Numerous applications were received from persons interested in participating in this program. Selection of the units was done on the basis of age, condition and efficiency. Four furnaces were finally chosen for retrofit, the cost of which was borne by the program in exchange for the homeowner's cooperation in monitoring through the season. Table B-1 gives specifications of these four units.

At weekly intervals following this work each of these furnaces was efficiency tested (using a Fuel Efficiency Monitor) and checked for smoke number. This was undertaken in order to monitor the decay, if any, of the steady state efficiency over the heating season. The data covers the period from late October 1983 to the end of May 1984.

9.2 Retrofit Measures

Each of the furnaces was first tested for efficiency and then thoroughly cleaned, after which testing was once again carried out. After approximately one week's time retrofitting was undertaken. Table B-2 lists the measures applicable to each furnace. A brief account of the work carried out and the problems encountered follows:

I. This unit was serviced by RPC staff. The procedure, which included cleaning, tune-up and retrofitting, took approximately 6 hours and had a cost in materials of about $50.00.

Difficulty was encountered when attempting to fit the retention head to the blast tube as it was not of sufficient diameter. This necessitated taking the component to RPC for spot welding, which naturally increased the length of the job. During this work it was noted that a defective humidifier was leaking water on to the heat exchanger and had actually pierced it in places. The unit was removed and the holes patched. The humidifier was not replaced.

II. Furnace number 2, as well as the subsequent furnaces, was serviced by a local plumbing and heating firm retained for this project. The procedure was similar; cleaning, tune-up and retrofitting.

Again, the retention head would not fit over the blast tube as intended and had to be welded onto the end. It was noted, however, that if this were done the overall length of the tube would be increased to the point where the nozzle/electrode assembly could not be properly positioned. To compensate, a shorter blast tube had to be secured before welding. Additional measures applied included replacement of the circulating fan belt with one of proper length and installation of a functioning barometric damper.

III. Of the four test furnaces this was the only hydronic unit. It was of cylindrical design with vertical tubes. As before, the retention head had to be welded in place. Additionally, the blast tube flange had to be cut with the torch and repositioned 2" back along the tube. This was necessary to negate the extension effect caused by the new end cone.

As Table B-2 indicates, no ceramic felt liner was installed. Fortunately, a factory built liner was already in place, as access to the chamber was very limited. Additional work included replacement of the transformer "buttons" and a set-back of the water temperature limits from 170°F/190°F to 160°F/180°F.

IV. The fourth and final furnace presented the same retention head/blast tube problems as previously encountered. However, after welding it was only necessary to install a double gasket between the blast tube flange and the furnace casing to compensate for the increase in length.

In this case the combustion chamber was seen to be in very poor shape, having cracked and crumbled in several places. The installation of a liner served not only to permit nozzle downsizing but it also restored the chamber to a "like-new" condition. This will undoubtedly prolong the life of the furnace.

9.3 Results

In Table B-3 the immediate results of both cleaning and retrofitting can be seen. At the beginning of the project the four test furnaces had an average efficiency of 69.5%, which was raised to 72.1% after a thorough cleaning. The retrofit of these units added another 6.8 points for a total of 78.9%. The overall improvement then was 9.4 points which compares very favourably with results obtained in the laboratory.

By the end of the season the furnaces, as a group, had suffered a decline in efficiency of 4.1 percentage points, although individually, two were better and two were worse (I 6.4, II 7.3, III 2.4 and IV 0.4).

Finally, once the monitoring had ended, the units were cleaned again in an attempt to restore efficiency to Fall 1983 levels. The following table indicates that in all but one case this was achieved. It also points out the importance of annual servicing.

Figures B-1 to B-4 display % steady state efficiency vs. time graphs for the four test furnaces.

In addition to improved efficiency, but as a direct result of it, there was also a decrease in fuel consumption during the 1983-1984 heating season when compared with the previous year. This figure (average) amounted to 496 litres.

	% Efficiency Fall 1983	% Efficiency End of Project	% Efficiency After Cleaning
I	77.1	70.7	76.9
II	78.9	71.6	72.2 *
III	81.6	79.2	81.7
IV	78.0	77.6	80.0

* Low due to a suspected poor cleaning job (the firm which did the initial work did not perform this final phase).

9.4 Cost-Benefit Analysis

In order to determine the savings to be derived from the retrofit program it was decided to choose the 1982-83 heating season as the base year and make all comparisons relative to this.

Heating degree day figures were obtained for 1982-83 as well as those currently available for 1984; this being to the end of May. The most recent comsumption figures were then adjusted to levels reflecting the temperature conditions of the base year.

Table B-4 lists the salient figures of the cost-benefit analysis. It should be noted here that in case III a basement hot-water heating loop was installed in the late summer of 1983. The data given still indicates a saving, albeit small, in spite of this addition. In order to make the proper comparison then, the effect of this loop must be accounted for and subtracted from the results of the overall system. In Table B-5 this has been done.

In each case there was a saving to be had from the retrofit program. An average of 496 litres of fuel or $176 was saved during the test period (1983 - 1984 heating season). Furthermore, this works out to an average simple payback period of 1.95 years.

10.0 CONCLUSIONS

From the description of the preceding work, it is evident that there is much to be gained by implementing an oil furnace retrofit program of a suitable degree for the particular application in question. There is no doubt that the majority of the currently installed furnaces are oversized and are also operating well below their maximum level of efficiency.

In the laboratory it was possible, by carefully selecting from numerous combinations of retrofit devices, to raise the efficiency of a 20 year old furnace from 62% to roughly 77%. Similarly in actual field trials average efficiency was increased 9.4 percentage points following cleaning and retrofitting.

11.0 RECOMMENDATIONS

This work can be summarized in the following series of steps which the homeowner might take or have taken in order to improve the performance of his oil-fired heating system.

1. Have the furnace thoroughly cleaned. This includes such things as the combustion air fan, electrode assembly, barometric damper, flue pipe, exhaust breeching, chimney base, heat exchanger and the circulating fan (hot air). In addition, the nozzle should be replaced, oil and air filters changed and the v-belt (if applicable) checked for wear and tension. There are also a number of other items with which the competent burner serviceman should concern himself. These include such things as inspection of electrical wiring, examination of the oil pump for leaks, examination of the photocell and the transformer terminal "buttons" and a general look at the exterior of the unit.

2. Have a flame-retention head installed if one is not already in place. This is step one of the retrofit process.

3. Determine the heating requirements of the house and compare with the present output of the furnace.

4. If the latter substantially exceeds the former, consider downsizing the nozzle to reduce the output of the furnace. Note: A reduction of one size is recommended in conjunction with a retention head. Also, this reduction will result in decreased oil consumption over the heating season.

5. If a nozzle reduction of more than one size is anticipated, investigate the possibility of installing a ceramic felt chamber liner in order to retain compatibility between nozzle capacity and combustion chamber dimensions. If the liner cannot be installed, such a nozzle downsizing is probably not wise. Note: If the present chamber is in a state of disrepair, a liner can extend its life by many years.

6. Look to installing a delayed action solenoid valve which will substantially limit smoke production at start-up and shut-down of the system.

7. Consider installation of a stack damper or a combustion air damper. The former device is capable of producing savings of 3-9%, with the higher figure being applicable in mild weather and the lower in cold weather (due to increased furnace on-time). No data is readily available on the latter device.

8. It should be noted that if the efficiency of the unit is already 75% or above then anything beyond a thorough cleaning will not be economically beneficial.

There still exists the possibility for future work in this area. It would be worthwhile to conduct a second retrofit program designed to assess the benefits of the automatic stack damper and the combustion air inlet damper. This could be done in conjunction with the previous retrofits as well as with a new set of test furnaces for comparison of the results.

PART III

Wood Furnace Test Program

12.0 BACKGROUND TO WOOD RESIDUE COMBUSTION EQUIPMENT TEST PROGRAM

Although the people of New Brunswick have always been historically predisposed to the burning of wood there is now, more than ever, an increasing trend towards using wood as a home heating fuel. With such incentives as the Canadian Oil Substitution Program (COSP) coupled with the pressures of ever-rising energy costs, wood burning has gained great popularity in the past few years. Because of this situation, there has of late been a significant amount of interest in utilizing the available wood supply to its best advantage. This has resulted in much effort being applied to the redesign of the traditional wood stove in order to improve its efficiency. Air-tight units, baffling to increase the length of the flame path and the development of the catalytic combustor to reduce harmful emissions are just some of the major innovations to hit the market during the past decade.

The gathering, storing and burning of stick wood is a labour-intensive process which can in no way match the convenience and ease of operation of a modern-day oil, gas or electrically powered furnace. The future in wood fuel use is to develop and market an economically viable automatic or semi-automatic wood residue stoker which would give the consumer the simple operation that he is used to.

On the surface this would seem to be a very attractive proposition for many reasons. It is well known that most sawmills in this province are plagued by an over-abundance of wood residues which are either left lying at the site or hauled away with the attendent expenditure of time and money. There is definite potential for the mill to use this waste in order to generate heating and/or process steam requirements and, in fact, in certain areas this is currently being done. A lucrative market is now developing in selling this hog fuel to other industrial or commercial clients, either for their own use or for distribution to domestic users.

Sawmills are not the only source of wood residues however. There are presently large volumes of dead-fall and bud-worm ravaged woods which could be chipped to supply this anticipated demand. This is attractive not only for its job creation potential but also for the fact that it would go a long way towards cleaning up our forests. Burning this waste wood in our homes is certainly preferable to using the premium stands of this province. The finished product market would undoubtedly benefit from this change in policy.

Unfortunately these things have not yet come to pass and a reliable supply of wood chips (or any other residue for that matter) for residential use is a difficult thing to come by.

A number of New Brunswick manufacturers are presently involved in the design and fabrication of wood-residue-burning equipment. However, as this work is being carried out on a small scale the manufacturer is not always in a position to provide a rigorous technical analysis of the equipment which may be needed to overcome the inherent problems. This has led then to a basically trial and error situation in which the manufacturer can only learn from his mistakes.

This state of affairs has made it difficult for these residue burners to gain widespread acceptance and has resulted in a rather long development period. Coupled with this, and quite possibly as a result of it, no locally manufactured wood chip or sawdust burner has yet received CSA certification, which would certainly boost sales by giving these applicances a good measure of credibility.

There is a further complicating factor, in that CSA does not have a standard for residue burners at this time. Still the N.B. manufacturers have not yet reached the stage where certification could feasibly be sought.

There are many questions which have not been satisfactorily answered concerning this technology. These include such things as what fuel type is best suited for the application, which range of moisture contents will produce the best combustion, what fuel type will be most satisfactory and how do efficiency and emissions compare to those generated by a log wood stove? Without the necessary data base it is very difficult for the consumer to make an intelligent choice when purchasing this equipment. Further, without a reliable fuel supply the situation becomes doubly complicated.

In order to assist the manufacturer by providing technical information and in so doing increase the use of wood residue fuels, RPC's Combustion Demonstration and Test Facility undertook the testing of two locally produced chip/sawdust burners.

13.0 TEST PROGRAM

13.1 Background

The test program was designed to evaluate the performance characteristics of two domestically sized, wood-residue combustors; one of the gravity feed type and the other fed by a pair of motor driven augers. It was decided to develop a useful data base for future investigation by examining the following parameters:

1. An evaluation of the unit's ability to properly feed a given type and size of residue as well as a variety of residue combinations.

2. An evaluation of the unit's ability to ultimately burn these residues and combinations of residues.

3. A determination of the average steady state efficiencies, thermal outputs and emissions achievable with the selected residues.

4. An evaluation of the effects of moisture content on all of the above, i.e.:
   a) Feed
   b) Combustion
   c) Efficiency
   d) Heat Output
   e) Levels of undesirable emissions.

5. A general survey of any mechanical difficulties or safety hazards observed during testing.

13.2 Test Equipment and Procedure

A prerequisite for this testing was the ability to monitor the consumption of fuel during a burn. This was accomplished by placing the burner on the platform of a Toledo Model 2155 weigh scale equipped with an 8132 Digital Indicator and a 0-10 volt option. This option permitted the scale's output signal to be fed to a Kaye Digistrip III programmable data logger which produced a printed record of the residue consumption throughout the test.

Steady state efficiencies were determined using a slightly modified version of the instantaneous heat loss method developed by CCRL (Canadian Combustion Reserach Laboratory) in which the percentages of the major flue gas constituents are continuously analyzed throughout the test. In this case oxygen (O_2), carbon dioxide (CO_2), carbon monoxide (CO) and hydrocarbons (HC) were monitored using Beckman gas analyzers. These latter two are, incidentally, excellent indicators of the completeness of combustion.

All this data, as well as that from an ambient temperature thermocouple and an array of five type K thermocouples in the stack, was fed to the Digistrip III where it was logged at 10 second intervals, averaged and printed every 5 minutes (operator's choice). In addition to producing a hard copy print-out of the information the data logger also fed it to a Hewlett-Packard HP-85 micro-computer for storage on magnetic tape from which it could later be retrieved by an efficiency calculation program.

After each test, once the furnace had cooled down, all ash and unburnt material was collected, weighed and sent to the lab for a determination of any remaining thermal content. This figure was then subtracted from the initial calorific value of the fuel in order to ascertain the correct energy input.

Table C-3 lists the test equipment used while Figure C-2 gives a schematic of the laboratory set-up.

13.3 Choice of Residues

A varied selection of wood residues, encompassing a wide range of moisture contents was gathered for this project. A sample of each was submitted for a determination of its calorific value and moisture content. Table C-1 lists the selected residues as well as the results of the laboratory analysis.

In addition each sample was broken down into its various size components in order to attach some type of classification to it. This information may be found in Table C-2. Figure C-1 shows photographs of these fuels.

It should be noted that although Douglas Fir (D.F.) is not native to the Atlantic region, it was available from some previous work and so was chipped for this project. It produced a dry, uniform and homogeneous chip whose inclusion among the other residues was considered to be worthwhile for calibration purposes. The Energex pellets, highly compressed biomass, were supplied free of charge by Bio Shell, Sherbrooke, P.Q. The remainder of the residues, all softwoods, were obtained from a local sawmill operation, again at no cost.

14.0 GRAVITY FED SAWDUST BURNER

14.1 Description

This appliance, a gravity fed sawdust and chip burner, consists of a burner assembly which protrudes significantly from the front of a standard design forced air furnace containing the heat exchanger and circulating fan. The integrated fuel hopper, which sits essentially over the combustion chamber, feeds the residue onto a grate in the chamber where firing takes place. An auxiliary sheet metal hopper, to be fitted on top of the original, is also available for this unit.

A small electrically powered blower circulates air around the fire box from which it may be ducted to the hot-air plenum of the furnace. The burner itself is hinged on one side and may be swung open for easy ash removal. There is also a small sliding door on the side of the unit to assist with this task or to view the condition of the fire during use.

Combustion air may be controlled at two points on this unit. Primary air is regulated by a motor operated, thermostatically activated flap damper on the front of the burner while secondary air is adjusted manually using a sliding damper on the rear of the burner. The temperature sensor for the flap damper is located in the hot-air plenum and responds to close the damper at 205°F. This is the only means of reducing the firing rate.

Figures D-2 and D-3 show, respectively, a photograph and a schematic diagram of the system.

14.2 Test Parameter Variations

In order to achieve a constant firing rate, an initial test was performed with the auto damper disabled in the open position. This led, however, to excessive temperatures throughout the system to the extent that the burner was observed to be glowing red in places and paint to be burning from the furnace. It was decided that this represented an abnormal as well as unsafe condition and that it would not be repeated in subsequent testing. Henceforth the damper was allowed to function as designed.

This left only one variable then, apart from fuel type and moisture content, to be experimented with and that was the position of the rear damper; either open or closed.

14.3 Test Procedure

After noting the tare weight of the burner itself, a known weight of residue was placed in the hopper. All instrumentation was then activated in order to record a set of zero condition readings. At this point the burner was swung away from the furnace, the bottom of the fuel pile ignited with a propane torch and the unit closed once again. The test was then allowed to proceed for approximately 1½ hours until the bulk of the fuel had been consumed.

Table D-1 lists the test data and final results of all work performed on this gravity fed burner. It will be observed that the moisture figures given here differ somewhat from those found in Table C-1. Even though the residues were plastic bagged in 50 lb. lots, it is to be expected that there would be some variation from bag to bag.

14.4 Results

14.4.1 Feed Properties

Initially this unit was equipped with a motor-driven combustion grate shaker whose purpose was to alleviate bridging problems in the hopper and thereby ensure a steady flow of fuel. According to the manufacturer, a shake interval of 10-15 minutes would be sufficient under most circumstances. It was found, however, during some initial experimentation, that this device produced very little improvement with the easy to feed residues and was of no use whatever with the difficult fuels, even set at continuous shake.

Prior to the start of the test schedule this device failed and as a replacement unit was not available testing proceeded without it. However, as it was the first model to be so equipped and as the shaker proved to be only marginally beneficial, its absence was not thought to be of importance.

Only two failures were encountered when testing this unit and those involved the use of bark and shavings. In the former case the length and stringiness of the bark prevented it from passing through the throat of the hopper. Quite probably its high moisture content added to this problem although even after being air dried to 15% moisture the feed characteristics improved only slightly. With shavings, their light fluffy texture would not allow proper feed. No amount of manual grate-shaking or stirring in the hopper would improve this situation.

It should be noted however that by mixing either of these two residues with a portion of chips or sawdust they could be made to feed quite satisfactorily, even in 2:1 ratios (by volume) in favour of the difficult to feed fuel.

14.4.2 Combustion

If the residue could be made to feed, burning it was not a problem. No difficulty sustaining the fire was ever encountered.

14.4.3 Efficiency of Combustion/Heat Output

Burner efficiencies ranged from a low of 47.5% to a high of 84.0% depending on fuel type and moisture content. Stack temperatures were reasonable, ranging between 197°C and 397°C.

Similarly, heat output varied from 72,000 Btu/hr to 380,000 Btu/hr. It is evident from the data in Table D-1 that the smaller the residue particles the faster the rate of feed and therefore, barring the effect of moisture, the greater the output of heat. Dry Douglas Fir chip fed at roughly 42 lb/hr while wet sawdust fed at 76 lb/hr on average.

14.4.4 Effects of Moisture Content

14.4.4.1 Feed Properties/Combustion

The amount of moisture in the fuel had little bearing on the way in which it fed. The prime factors affecting flow were physical dimensions and textures.

Combustion was sustained irrespective of moisture content once the fuel had been made to feed. Even at moisture levels approaching 40% this held true. The only difference between a wet or dry fuel was the fact that with the former it took somewhat longer for the system to reach a steady state condition.

14.4.4.2 Efficiency/Output

The steady state portion of a given set of test data was utilized when calculating efficiencies. This usually started 10-20 minutes into the burn when stack temperatures and flue gas readings became essentially constant, and lasted some 30 minutes.

Tests 1-4 were performed using Douglas Fir chips with an average moisture content of 13%. All efficiencies but number 2 were in the area of 80% regardless of the rear damper setting. In the case of test 2, the front damper was wired in the open position, resulting in the excessive stack and shell temperatures discussed earlier. This was undoubtedly the cause of the lower efficiency encountered (68%).

Tests 5-8 involved the use of a 38.4% moisture content sawdust. All three tests yielded efficiencies of approximately 50%.

Examination of the data in Table D-1 leads to the conclusion that efficiency is definitely moisture dependent. In Table D-2, five ranges of moisture are listed along with the number of samples in each range and their corresponding efficiencies. Up to about 16% moisture, efficiencies are generally in the low 70's while after this point they drop off significantly. This is shown graphically in Figure D-1.

14.4.4.3 CO/HC Emissions

Table D-3 lists four residue types used in testing this burner and their corresponding average moisture, CO and HC levels. It is evident that as the moisture content of the residue increases so do the levels of carbon monoxide and hydrocarbons. The only notable exception is seen when comparing the Energex pellets to the Douglas Fir chips, although the discrepancy is negligible and probably has to do with the higher density of the pellets.

At 38.4% moisture CO levels are 7.4 times higher and HC levels 10.1 times higher than at 9.8% moisture. As the chemical make up of these woods do not differ drastically the increase in emmissions is undoubtedly due to high water content preventing proper combustion.

14.4.5 Mechanical Design/Safety Considerations

The fact that the fuel hopper sits directly above the area of combustion implies that burn-back could be a serious problem with this design and, in fact, this is the case. A test was conducted in which a fire was well established and then all electrical power to the system cut. Within ½ hour the flame had travelled approximately one third of the way up the hopper, indicating a significant safety hazard.

It was found that the fire was drawing much of its combustion air through the fuel supply and thus it was possible, by sealing the top of the hopper, to reduce the burn-back problem substantially. This was of course only a temporary solution and its implementation would require a major redesign of the system. Feeding the hopper would become more difficult and there would be no guarantee that the homeowner would always remember to replace the air tight cover.

As the burner is of the gravity fed type there is no control over the rate of feed of the fuel and consequently no way to conveniently vary its heat output.

14.5 Conclusions

This burner is capable of feeding any fuel but shavings or bark. It is also capable of combusting these fuels, some with moisture contents as high as 40%, without difficulty. Beyond 40% results are unknown. Steady state efficiencies of 80% are possible when utilizing dry chips (~13% moisture).

High levels of moisture do interfere with the quality of combustion, leading to reduced efficiencies and increased emissions of CO and HC.

The design of this burner indicates that it may represent a serious fire hazard. Coupled with the fact that no real safety features or devices are included as part of the package makes it unlikely to receive CSA certification (assuming the development of an appropriate standard in the near future) without some modification.

15.0 AUTOMATIC CHIP STOKER SYSTEM

15.1 Description

This automatic system consists of two components, the chip stoker, and a wood-burning hot-air or hot water furnace. For test purposes a complete system was purchased; the stoker and a modified Fawcett WF-90 warm-air, wood-fired furnace. The modification was necessary to accomodate the combustion bowl and an ash removal drawer beneath the combustion chamber.

The stoker consists of a 16 cubic foot hopper from which the fuel is taken by an upper, motor-driven auger and dropped into a transfer box. A second auger, driven by the same system, carries the residue to a combustion bowl which resides inside the combustion chamber of the furnace. The feed rate may be varied by changing the diameter of the motor pulley.

The bowl supplied with this system was of hollow wall construction; 11" O.D. and 9 3/4" I.D. From its floor to the top edge it was 3 3/4" in height except near the middle where the floor sloped upward from the auger tube to which it was attached.

Around the inside top edge of the bowl were 62, 1/8" holes on ½" centers. The flat section of the floor contained 18, 3/16" holes on 1" centers. A small blower, housed under the hopper and activated each time the feed system came on, supplied air to these two sets of holes. Two small adjustable dampers situated on the auger tube provided control of the air supply so that the proper ratio of over-fire combustion air (OFCA) to under-fire combustion air (UFCA) could be achieved.

In an actual residential situation the system cycles on and off at the command of a standard thermostat. The difficulty here is that during the off time of the cycle, the fire may go out. To circumvent this the stoker is equipped with a pair of timers which allow the user to feed small amounts of fuel at preset intervals for a preset duration in order to keep a pilot flame or embers always present in the bowl. The timers are adjustable so that the heating requirements of the house can be adequately met no matter what the season.

A photocell is also present in the system in order to shut down the transport of fuel should a fire fail to be established in the combustion bowl.

The hopper is equipped with a 2 gallon water reservoir which is temperature activated to release its charge if burn-back should occur in the auger tube.

Figures E-2 and E3 present, respectively, a schematic diagram and photographs of this system.

15.2 Test Parameter Variation

In all of these tests the unit was allowed to run continuously. Various residues were attempted and in each case the OFCA and/or UFCA settings were adjusted.

The residues used here were the same as those employed with the gravity fed burner, details of which can be found in Tables C-1 and C-2.

15.3 Test Procedure

Once again a known weight of residue was placed in the hopper and the augers run until a quantity began to appear in the bowl. At this point all instrumentation was switched on in order to record a set of initial readings. The fuel was lit with a propane torch and the burn left to run its course which took approximately 1 ½ hours.

A summary of all the principal test results may be found in Table E-1.

Once again note should be taken of the variance of the moisture figures from Table C-1 to Table E-1. As time went by and these residues were exposed to the air their moisture contents steadily decreased. Table C-1 simply records their condition as initially received.

15.4 Results

15.4.1 Feed Properties

As with the previous burner, shavings could not be made to properly feed from the hopper. No amount of agitation was of benefit and only minimal transport down the auger tubes was observed, not nearly enough to sustain fire.

Bark also presented a problem in that it had to be stirred in the hopper at 10-15 minute intervals in order to overcome the bridging problem.

The Energex wood pellets proved to be troublesome in the opposite manner. The feed rate of the stoker was excessive for this type of fuel and combustion could not keep pace. The end result was that partially burned pellets were spilling from the bowl into the ash drawer. Since all tests were performed with the feed rate as set by the manufacturer no attempt was made to decrease it in order to accomodate these pellets. Had this been done there is no doubt that they would have made an excellent fuel.

As before, mixing the pellets with another residue allowed proper feed to be achieved. However, contrary to the gravity fed experience, shavings still would not work, even when mixed in a 2:1 ratio with Douglas Fir chips.

Apart from the above, all other residues and combinations of residues were handled with relative ease with only minor occurrences of bridging taking place. It must be remembered though that these runs lasted only 1 ½ hours.

15.4.2 Combustion

It appears that the factory set feed rate of this stoker is now near its maximum. Any increase, given the bowl size and air flows, would undoubtedly result in spillage.

All residues that could be successfully fed could also be successfully burned by this system.

15.4.3 Efficiency of Combustion/Heat Output

The stoker system produced efficiencies which varied from 55.0% to 84.3%, again depending on fuel type and moisture content.

Correspondingly heat outputs also showed a marked variation, ranging from 48,000 Btu/hr to 200,000 Btu/hr. In this case feed rate was the controlling factor. The former figure was obtained using bark which fed at roughly 8 lbs/hr, while the latter involved a mixture of Douglas Fir chips and pellets which fed at 30 lbs/hr.

Table E-2 lists the settings of the UFCA/OFCA dampers and the average efficiencies obtained at them. It is concluded that although efficiencies were marginally better at the lowest air settings, the relative positions of the dampers have little effect on the figures.

15.4.4 Effects of Moisture Content

15.4.4.1 Feed Properties/Combustion

Any fuel that could be fed with this system could also be combusted by it even at moisture contents as high as 37%. Beyond this its capability is unknown.

The higher the moisture content of the residue the longer it took to reach steady state.

15.4.4.2 Efficiency/Output

Although the average burn lasted 90 minutes only the steady state period (constant stack temperature and gas readings) of approximately 45 minutes was used for this work.

Testing proceeded differently with this burner. Tests 1-7 consisted of burning each residue separately one at a time while the next set used various combinations of these residues as fuels. Following this a half dozen tests were performed using only Douglas Fir chips but varying the settings of the combustion air dampers. Finally, the moisture contents of two charges of Douglas Fir were significantly increased in order to observe any changes in feed properties, efficiency or quality of combustion. Figure E-1 shows graphically the relationship between moisture and efficiency.

Again there is no doubt that the quantity of moisture contained in the fuel had a direct influence on the steady state efficiency (47.5% - 80.0%) as well as on the heat output (72,000 Btu/hr - 380,000 Btu/hr).

Table E-3 lists the efficiency/output results obtained using Douglas Fir chips at various levels of moisture.

15.4.4.3 CO/HC Emissions

As the sequence of Douglas Fir tests represents the only major variation of moisture contents it was examined relative to the question of emissions. Table E-4 indicates that as moisture increases so do the emissions; 160 times for CO (from 11.8% - 36.6% moisture) and 180 times for HC.

15.4.4.4 Mechanical Design/Safety Considerations

With this design the fuel hopper is not situated near the area of combustion and consequently the hazard of a serious fire is small. Burnback in the auger tube is a recurring problem with this unit although under normal operating conditions it does not pose a major threat. Even under power outage conditions when fire did proceed up the entire length of the lower tube, the safety mechanism supplied, consisting of a water dousing system, was effective in quenching the flame.

The mechanics of this stoker provide some control over the rate of feed of the residue and hence the output of heat. By adjusting the size of the motor pulley it is possible to vary the amount of fuel travelling to the bowl.

Bridging of the fuel supply in the hopper is a potential problem although it did not hamper the tests in any way because of their short duration. It is understood that at the present time the manufacturer is supplying a variable intensity vibrator on the hopper to alleviate this situation.

Stack temperatures encountered during this work were quite reasonable, rarely rising above 300°C. This compares favourably with the recommended limits for an oil-fired furnace of 175°C - 400°C.

15.4.5 Conclusions

This particular stoker system is capable of combusting any residue that can be fed satisfactorily from its hopper. This excludes shavings however (too light to feed), even when mixed with other wood residues. Bark did feed although poorly with many indications that it was jamming in the auger tube as it went. All other fuels and combinations of fuels tested produced no significant problems though it is suggested that the feed rate be somewhat reduced when utilizing compressed biomass pellets.

Elevated levels of moisture (to the 40% examined) do not prevent combustion although it is slower starting and is attended by an increase in the emission of carbon monoxide and hydrocarbons.

With a relatively dry residue this stoker-furnace combination is able to produce steady state efficiencies in the range of 75%. Again this figure compares quite favourably with those generated by an oil-fired system. Further, the use of residue fuels is more efficient and produces fewer emmissions than the combustion of log wood.

	Residue Burning	Log Burning
Efficiency %	81 *	74 **
% CO ***	0.31	0.76
% HC ***	0.05	0.34

* Maximum encountered in this work (average of six 80% + readings)

** Average obtained from:
Hayden, A.C.S. and Braaten, R.W., "Effect of Wood Stove Design on Performance", Division Report ERP/ERL 80-46 (OP), March 1980, p. 8

(Average of the three airtight designs)

*** Residue figures obtained from average of 13 Douglas Fir Tests, moisture content 12%, wide open burn. Log figures obtained from average of 5 Douglas Fir 2" X 4" Tests, moisture content 13%, wide open burn, Lakewood stove. These were performed after completion of the residue test work for comparative purposes.

16.0 RECOMMENDATIONS

It would be worthwhile to further utilize the two-wood residue combustors tested to investigate the effects of fuels with moisture contents above 40%. Feed characteristics, efficiency, heat output and emissions would be examined. In particular the emissions testing would be expanded to include particulates and polycyclic organic materials (POM's). Comparison with similar data already available on stick wood burners would be useful in establishing residue combustion as the superior way to utilize wood as fuel. This would lead then to the specification of a method of testing and rating these combustors; something which is lacking at present.

Creosote buildup is another area which bears examination. Comparison with data obtained from the testing of log-wood stoves and furnaces needs to be undertaken.

Combinations of various wood residues and peat could form the basis of a beneficial project as this province possesses extensive peat reserves which could be utilized in this manner.

Taking the previous suggestion a step further, there is need to develop a universal biomass fuel which would be suitable for a range of combustion systems. This would entail producing a fuel of uniform shape, size and moisture content, suitable for automatic stoking and combustion in either commercial or residential appliances.

Finally, the stoker system itself needs upgrading in order to overcome specific problem areas, and in do doing become a reliable, economically attractive unit. This would include increasing its output substantially so that it could meet the needs of institutional or small commercial clients where it is estimated the immediate market lies.

PART IV

Information Transfer

17.0 INFORMATION TRANSFER

After completion of the oil furnace retrofit work, it was decided to produce a video-taped account of this procedure for use at future seminars. In fact, this turned out to be a half hour, three segment production dealing with the cleaning, servicing and retrofitting of a common oil-fired system.

In preparation for a planned evening seminar, Mr. Ray Falconer of the New Brunswick Community College, St. Andrews, was engaged as the guest speaker. Mr. Falconer has for many years taught the oil burner service course with the Community College. Advertisements were placed in the Fredericton newspaper as well as on the local CBC radio station. Approximately 40 responses were generated by this and as only 20 persons could be comfortably accommodated at RPC's conference facilities at any one time, a second seminar was arranged for a later date.

On the evening of October 17, 1983, the first seminar took place. Of the 20 attendees, the majority were homeowners although there were two or three burner servicemen present. Following a brief introduction, the video tape was shown after which Mr. Falconer took the floor in order to expand upon the points presented and field questions from the audience.

The remainder of the presentation took place in the combustion laboratory where a number of oil furnaces and retrofit devices were on display. One furnace had been fitted with a glass viewport so that the combustion chamber could be observed while firing took place. Demonstrations were given on such things as nozzle replacement, electrode assembly adjustment and the use of a Bacharach Combustion Test Kit. In addition, a brief overview of the facilities wood residue projects was given.

A CBC television reporter and camera crew were also in attendance throughout the evening to prepare a report on the seminar and oil furnace tune-up in general. It was shown a few weeks later as part of the consumer report segment of the evening news.

At the end of the presentation, which lasted approximately four hours, printed material was handed out. This included a copy of the video script, a list of retrofit devices and their approximate costs, the EMR publication The Billpayer's Guide to Heating Systems and Make the Most of Your Heating System (Ontario Ministry of Municipal Affairs and Housing). As well, a questionnaire was circulated in order to gauge the response of those attending.

On November 17, the second seminar was held, again with approximately 20 people attending. The format was similar and as in the previous case all participants, without fail, indicated their satisfaction with the evening.

Judging by the interest shown in the Fredericton area, it was felt that, time and funds permitting, this presentation could be taken to other parts of the province. To date, however, this has not been done.

Access to the Combustion Demonstration and Test Facility was also available through a number of tours which were scheduled during 1983-1984. Although these tours were of RPC in general, time was allocated for the combustion laboratory itself. A brief talk and demonstration, lasting anywhere from 5-40 minutes, was presented. The following list summarizes the principal tours occurring during this period.

Date	Group	No. of Persons
Apr. 15/83	Grade 9 students, George St. Junior High	30
May 12/83	Chemistry Technology Students, NBCC	30
June 20/83	NBCC Instructors	6
Sept. 28/83	Industrial Manpower Advisory Commission, Committee on Mining, Dept. of Labour	17
Jan. 30/84	Industrial Education Dept., Dept. of Education, UNB	22
Feb. 28/84	Wood Energy Symposium Attendees	50
	TOTAL	155

There were also numerous visits from individuals interested in specific heating systems or areas of combustion. All in all, some 200 people were directly served by the CDTF.

It was anticipated that courses or seminars designed to upgrade the skills of the oil-burner serviceman would be conducted in conjunction with the New Brunswick Community College. However, after much discussion, during which the idea was enthusiastically met, implementation of this program did not come to pass. Apparently NBCC was not able to modify their curriculum rapdily enough to accommodate these plans.

APPENDIX A

OIL FURNACE TEST PROGRAM

EFFICIENCY CALCULATION

1. Ultimate analysis: C 85.52 — 19,243 Btu/lb
   H 11.81
   N 0.09
   S 0.18

2. Stoichiometric air required:

Combustible	O_2 From air, lb.	
$C = \frac{15.999 \times 2}{12.011} \times 0.8552$	2.2783	for CO_2
$H_2 = \frac{15.999 \div 2}{1.008} \times 0.1181$	0.9372	for H_2O
$S = \frac{15.999 \times 2}{32.064} \times 0.0018$	0.0018	for SO_2
	3.2173	Total O_2 from air lb/lb
Associated $N_2 = \frac{76.85}{23.15} \times 3.2173 =$	10.6803	
Grand Total	13.8976	dry air lb/lb oil

3. Stoichiometric Products (Dry Basis)

Dry Products		Wet Products
CO_2 0.8552 + 2.2783 =	3.1335	
N_2 =	10.6803	
SO_2 0.0018 + 0.0018 =	0.0036	H_2O 0.1181 + 0.9372
Dry Flue Gas lb/lb	13.8174 +	1.0553 = 14.8727
		Total Flue Gas lb/lb

4. Excess Air

e.g. $O_2 = 12.60\%$
$CO_2 = 5.77\%$
$CO = 0.0024\%$
$N_2 = 100 - (O_2\% + CO_2\% + CO\%) = 81.63\%$

$$\text{Excess Air \%} = \frac{100\ (O_2 - CO/2)}{0.264\ N_2 - (O_2 - CO/2)}$$

$$= 140.7\%$$

5. Additional Products Due to Excess Air

Additional $O_2 = 1.407 \times 3.2173 = 4.5267$
$N_2 = 1.407 \times 10.6803 = 15.0272$
19.5539 lb/lb oil

6. Total Products of Combustion

Total dry products = 19.5539 + 13.8174 = 33.3713 lb/lb oil
Total products = 19.5539 + 14.8727 = 34.4266 lb/lb oil

7. Dry Flue Gas Loss

$$\text{Loss Btu/lb oil} = \frac{\text{lb dry gas}}{\text{lb oil}} \times 0.24 \times (\text{Tstack-Tamb.})$$

$$= 33.3713 \times 0.24 \times (462°F - 76°F)$$

$$= 3091.52$$

$$\text{\% Loss} = 3091.52 \times \frac{100}{19{,}243\ \text{Btu/lb}}$$

$$= 16.1\%$$

8. Loss Due to H_2O From Combustion of H_2
Stack Temp. Below 575°F

$$\text{Loss Btu/lb oil} = 9 \times \frac{\text{lb H2}}{\text{lb oil}} \times [1089 - \text{Tamb} + (0.46 \times \text{Tstack})]$$

$$= 9 \times 0.1181 \times [1089 - 76 + (0.46 \times 462)]$$

$$= 1302.61 \text{ Btu/lb}$$

$$\% \text{ Loss} = 1302.61 \times \frac{100}{19{,}243} = 6.8\%$$

Note: If stack temp is above 575°F.

$$\text{Loss} = 9 \times \frac{\text{lb H2}}{\text{lb oil}} \times [1066 - \text{Tamb} + (0.50 \times \text{Tstack})]$$

9. Loss Due to CO

$$\text{Loss Btu/lb oil} = \frac{CO}{CO_2+CO} \times 10160 \times \frac{\text{lb carbon}}{\text{lb oil}}$$

$$= \frac{0.0024}{5.77+0.0024} \times 10160 \times 0.8642 = 3.651 \text{ Btu/lb}$$

$$\% \text{ Loss} = 3.651 \times \frac{100}{19{,}243} = 0.02\% \text{ ie negligable}$$

10. Efficiency % = 100 - (3 + 16.1 + 6.8) = 74.1%
Note: 3% is estimated loss due to radiation.

TABLE A-1
EQUIPMENT LIST

Gas Analyzers

Beckman Model 755 Paramagnetic oxygen
Beckman Model 864-23 CO_2 Infrared
Beckman Model 864-X CO Infrared
Beckman Model 400 Hydrocarbon
Beckman Model 951A NO/NO_x
Teledyne Model 611 DAMC SO_2 Photometric

Data Logger

Kaye Digistrip - III, programmable microprocessor controlled

Computer

Hewlett-Packard HP-85 microcomputer

Thermocouples

Type K

Air Flow/Pressure

MP6K8 Digital Micromonometer, Air Instrument Resources Ltd.
Air Velocity Meter, Model 1650, tsi

Figure A-1

Oil Test Schematic

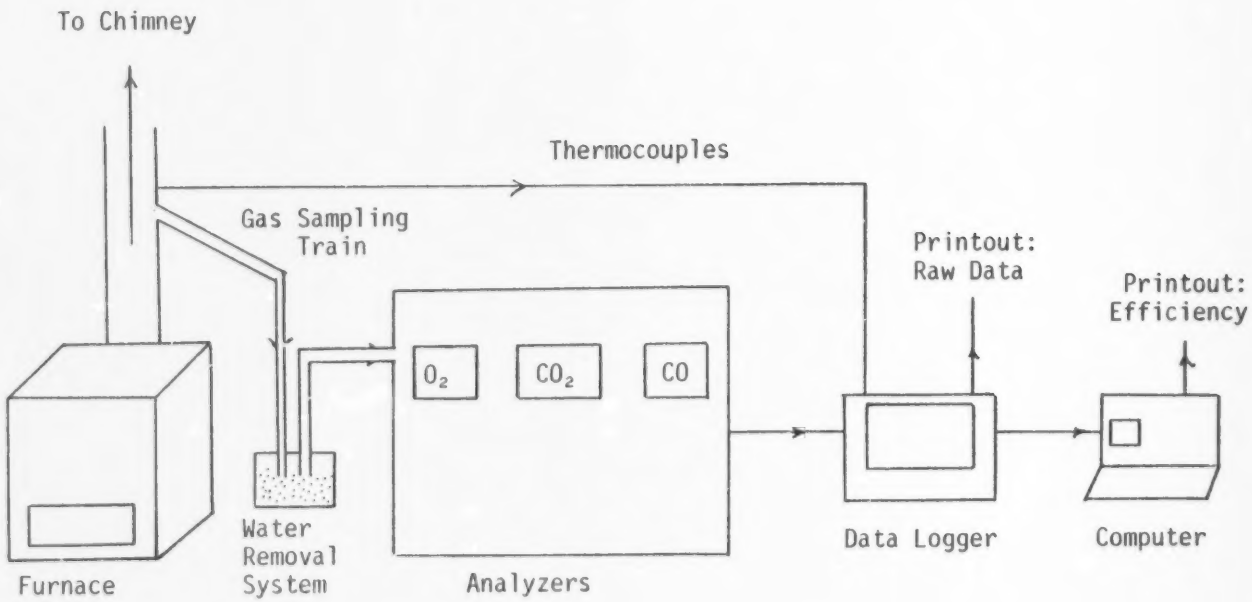


TABLE A-2
GUIDE TO NOZZLE SPECIFICATIONS

Hollow	Solid	Semi-Solid
H	R	ES
A	B	W
NS		

TABLE A-3

OIL FURNACE TEST RESULTS

Nozzle	% Efficiency	After Cleaning	Retention Head	0.85-1.25 Liner	0.75-1.00 Liner
0.55 90 W	59.0	64.1	67.0	73.3	76.0
0.60 80 R	62.9	70.6	71.9	73.3	76.3
0.60 80 NS	--	67.5	71.5	70.3	75.0
0.65 60 H	63.3	69.8	74.1	73.3	76.9
0.65 60 R	63.1	71.9	74.6	73.8	77.2
0.65 80 H	--	63.6	72.8	72.4	74.2
0.65 80 R	--	65.3	67.5	74.0	76.7
0.65 80 A	--	67.0	67.0	72.8	76.5
0.65 80 ES	62.0	65.1	69.9	73.6	75.9
0.75 60 H	65.2	72.8	74.9	75.7	77.0
0.75 80 H	63.6	69.5	75.9	73.6	76.1
0.75 80 R	64.0	68.6	79.8	73.2	77.1
0.75 80 B	63.1	68.7	76.0	73.9	77.3
0.85 60 H	63.1	70.4	76.2	76.2	76.8
0.85 60 R	63.0	70.6	76.1	74.5	76.7
0.85 80 H	62.5	70.6	69.5	74.6	76.0
0.85 80 ES	63.5	67.2	68.8	74.7	76.3
1.00 60 H	--	70.9	76.1	73.5	75.7
1.00 60 ES	67.9	68.0	75.8	73.8	75.8
1.00 80 H	68.7	66.0	75.9	74.0	75.0
1.00 80 ES	--	65.5	76.0	73.2	75.4
1.00 80 AR	68.6	68.0	76.1	74.2	75.7
1.10 60 H	69.2	72.1	75.8	73.7	75.4
1.10 80 ES	67.0	69.1	75.6	74.3	75.1
1.20 60 H	69.1	69.8	76.0	73.5	75.7
1.20 60 ES	68.7	71.0	75.9	73.5	74.9
1.25 60 H	68.0	69.9	76.0	73.3	74.8
1.25 80 AR	67.6	69.9	75.9	72.9	74.5

TABLE A-4: EFFICIENCY BY NOZZLE CAPACITY

Nozzle Capacity USGPH	Average : Eff. % Initial	Av. Eff. % After Cleaning	Av. Eff. % After Ret. Head	Av. Eff. % 1st Liner *	Av. Eff. % 2nd Liner **
0.55	59.0	64.1	67.0	73.3	76.0
0.60	62.9	69.1	71.7	71.8	75.7
0.65	62.8	67.1	71.0	73.3	76.2
0.75	64.0	69.9	75.7	74.1	76.9
0.85	63.0	69.7	72.7	75.0	76.5
1.00	68.4	67.7	76.0	73.7	75.5
1.10	68.1	70.6	75.7	74.0	75.3
1.20	68.9	70.4	76.0	73.5	75.3
1.25	67.8	69.9	76.0	73.1	74.7

* At this point the retention head was still in place

** This liner replaced the first one

Table A-5 - Test Results - Furnace 2

Nozzle	% Efficiency	Best Spray Angle	Best Spray Pattern
0.60 80 R	80.2		
0.60 80 NS	80.8		Hollow
0.65 60 H	81.5 (Maximum)		
0.65 60 R	81.3		
0.65 80 H	78.8	60°	Hollow
0.65 80 R	76.0		
0.65 80 ES	77.8		
0.75 60 H	80.6		
0.75 80 H	77.4		
0.75 80 R	79.4	60°	Solid
0.75 80 B	79.5		
0.75 80 ES	76.9		
0.85 60 H	79.9		
0.85 60 R	79.3	60°	Solid
0.85 80 H	78.3		
0.85 80 ES	78.4		
1.00 60 H	79.0		
1.00 60 ES	79.1	60°	Semi
1.00 80 H	78.0		
1.00 80 ES	80.0		

Note: Best by capacity

a) Highest individual - 0.65
b) Highest average - 0.60

TABLE A-6: EFFICIENCY BY SPRAY ANGLE *

Nozzle Capacity	Spray Angle	% Efficiency Initial	After Cleaning	Ret. Head	1st Liner	2nd Liner	Average Efficiency %
0.65	60	63.2	70.9	74.4	73.6	77.1	71.8
	80	62.0	65.3	69.3	73.2	75.8	69.1
0.75	60	65.2	72.8	74.9	75.7	77.0	73.1
	80	63.6	68.9	75.9	73.6	76.8	71.8
0.85	60	63.1	70.5	76.2	75.4	76.8	72.4
	80	63.0	68.9	69.2	74.7	76.2	70.4
1.00	60	67.9	69.5	76.0	73.7	74.8	72.4
	80	68.7	66.5	76.0	73.8	75.4	72.1
1.10	60	69.2	72.1	75.8	73.7	75.4	73.2
	80	67.0	69.1	75.6	74.3	75.1	72.2
1.25	60	68.0	69.9	76.0	73.3	74.8	72.4
	80	67.6	69.9	75.9	72.9	74.5	72.2

* Nozzles of capacities 0.55, 0.60 and 1.20 USGPH are not included here as only one spray angle was available for each.

TABLE A-7: % EFFICIENCY BY SPRAY PATTERN

Nozzle Capacity	Solid	Hollow	Semi	Best
0.60	73.0	71.1	--	Solid
0.65	72.6	72.1	71.1	Solid
0.75	71.8	72.4	--	Hollow
0.85	72.2	71.6	70.1	Solid
1.00	72.5	73.4	72.9	Hollow
1.10	72.2	73.2	--	Hollow
1.20	--	72.8	72.8	Hollow/Semi
1.25	72.2	72.4	--	Solid/Hollow

TABLE A-8: IMPROVEMENT DUE TO RETENTION HEAD

Nozzle Capacity	Improvement - Efficiency - Average Percentage Points
0.55	2.9
0.60	2.7
0.65	3.9
0.75	5.8
0.85	3.0
1.00	8.3
1.10	5.1
1.20	5.6
1.25	6.1
Average overall Efficiency Improvement	4.8

TABLE A-9: EFFICIENCY IMPROVEMENT DUE TO LINERS

Nozzle Capacity	Improvement - Percentage Points I	II
0.55	6.3	9.0
0.60	0.1	4.0
0.65	2.3	5.2
0.75	-1.6	1.2
0.85	2.3	3.8
1.00	-2.3	-0.5
1.10	-1.7	-0.4
1.20	-2.5	-0.7
1.25	-2.9	-1.3
Average	0.0	2.3

Note: This table is based on data contained in Table A-3.

TABLE A-10: PRESSURE VARIATION VS EFFICIENCY

Ret. Head (0.65 - 1.1), Liner (0.75 - 1.00

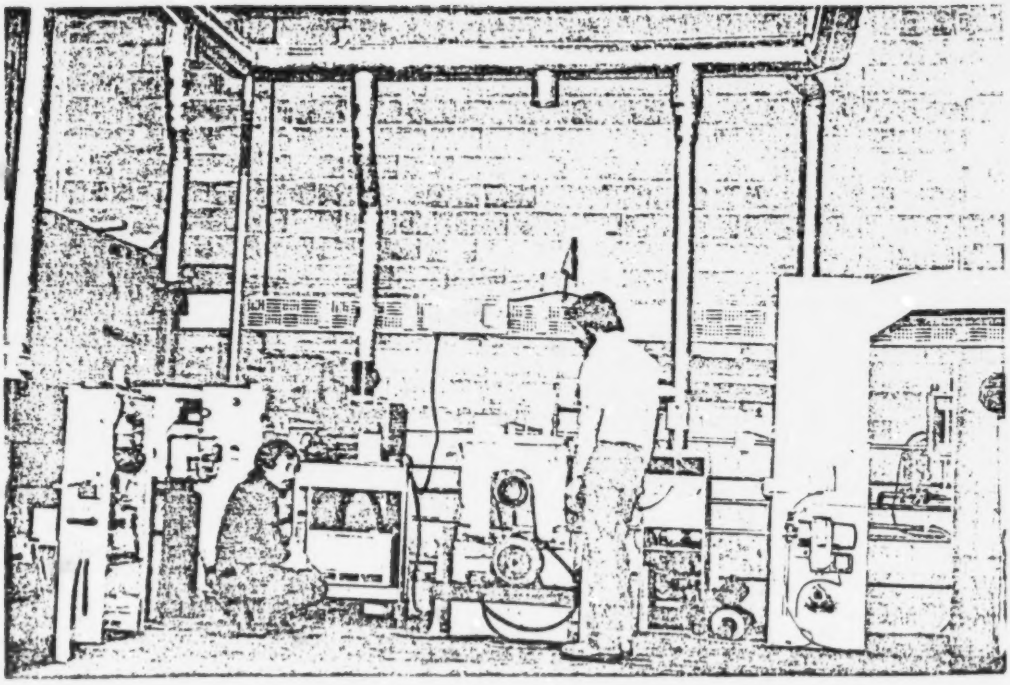
Nozzle	60psi		80 psi		100 psi		120 psi		140 psi	
0.65 60 H	67.2		73.1		76.9		75.6		--	
0.65 60 R	--		--		77.2		--		--	
0.65 80 H	--	71.1	--	74.6	74.2	76.0	75.5	75.6	76.0	75.6
0.65 80 ES	75.0		76.1		75.9		75.7		75.1	
0.75 60 H	74.0		75.1		77.0		75.4		76.4	
0.75 80 H	74.9	75.0	75.9	75.9	76.1	76.7	75.7	75.9	75.1	75.9
0.75 80 R	76.0		76.7		77.1		76.5		76.3	
0.85 60 H	75.0		76.4		76.8		76.1		75.7	
0.85 60 R	74.2		76.3		76.7		75.6		75.1	
0.85 80 H	75.9	75.4	75.9	76.2	76.0	76.4	75.7	75.5	75.4	75.2
0.85 80 ES	76.7		76.3		76.3		74.6		74.6	
1.00 60 H	75.2		75.4		75.7		75.8		75.3	
1.00 60 ES	76.5		76.4		75.8		76.1		75.8	
1.00 80 H	77.1	76.2	75.3	75.7	75.0	75.5	74.9	75.9	74.7	75.7
1.00 80 ES	75.9		76.7		75.4		76.6		76.2	
1.00 80 AR	76.2		74.6		75.7		76.1		76.5	
Average	75.0%		75.7%		76.1%		75.7%		75.6%	

Note: Figures to the right of each group are the average for that particular group.

Figure A-2

Photograph of Combustion Facility showing oil and gas furnace test area.

Figure A-2



Photograph of Combustion Facility showing oil and gas furnace test area.

APPENDIX B

RESIDENTIAL RETROFIT

TABLE B-1: Residential Test Furnace Specifications

	I	II	III	IV
Furnace make	Irving (Enheat)	Fawcett	Freco	Smart's
Furnace type	hot-air	hot-air	hot-water	hot-air
Age	20	10	12	11
Output (Btu/hr)	95,000	140,000	131,000	110,000
Burner make	Fawcett	Fawcett	Fess	Smart's
Specified nozzle	0.85 60°Solid	1.25 80°AR	1.25 80°R	0.65-1.00 80°Solid
Actual nozzle	0.85 90° Solid	1.25 80°AR	1.25 80°R	1.00 80°B
Pump make	Inglis-Sundstrand	Inglis-Sundstrand	Webster	Inglis-Sundstrand
Pump pressure (psi)	110	100	100	106
Efficiency (%)	68.0	71.3	69.8	68.7
Oil-fired water heater	No	Yes	No	Yes
Back-up source	elec. baseboard	wood stove	None	wood stove

TABLE B-2: Retrofit Measures

	I	II	III	IV
Cleaning	Yes	Yes	Yes	Yes
Retention head	AFC-2	AFC-2	AFC-2	AFC-2
Chamber liner	0.75-1.00	1.00-1.25	No	0.75-1.00
New nozzle	0.75 80°R	1.00 80°AR	1.00 80°W	0.75 80°W
Delayed action solenoid valve	No	Yes	Yes	Yes

TABLE B-3: Results of Cleaning and Retrofit

Furnace	Initial Efficiency %	After Cleaning	After Retrofit	End of Season	Final Cleaning
I	68.0	71.6	77.1	70.7	76.9
II	71.3	72.4	78.9	71.6	72.2
III	69.8	73.9	81.6	79.2	81.7
IV	68.7	70.6	78.0	77.6	80.0
Average	69.5	72.1	78.9	74.8	76.2

TABLE B-4: Cost-Benefit Analysis

Furnace	I	II	III*	IV
Oil Consumption (l) 1982-1983	2191	2630	4086	1946
Oil Consumption (l) 1983-1984	1844	2455	4275	1567
Degree Days 1982-1983	4242.6	4242.6	4242.6	4242.6
Degree Days 1983-1984	4536.3	4536.3	4536.3	4536.3
Adjusted Consumption (l) 1983-1984	1725	2296	3998	1466
Savings (l)	466	334	88	480
Savings ($)	164.50	117.90	31.06	171.84
Cost of Retrofit ($)	200.00	448.60	271.14	295.09
Simple Payback Period (Yrs)	1.2	3.8	8.7	1.7

* TABLE B-5: Case III Adjusted Figures

Adjusted Consumption (l) 1983-1984	3382
Savings (l)	704
Savings ($)	249.00
Cost of Retrofit ($)	271.14
Simple Payback Period (Yrs)	1.1

Figure B-1

FURNACE I

Efficiency vs Time

Figure B-2

FURNACE II

Efficiency vs Time

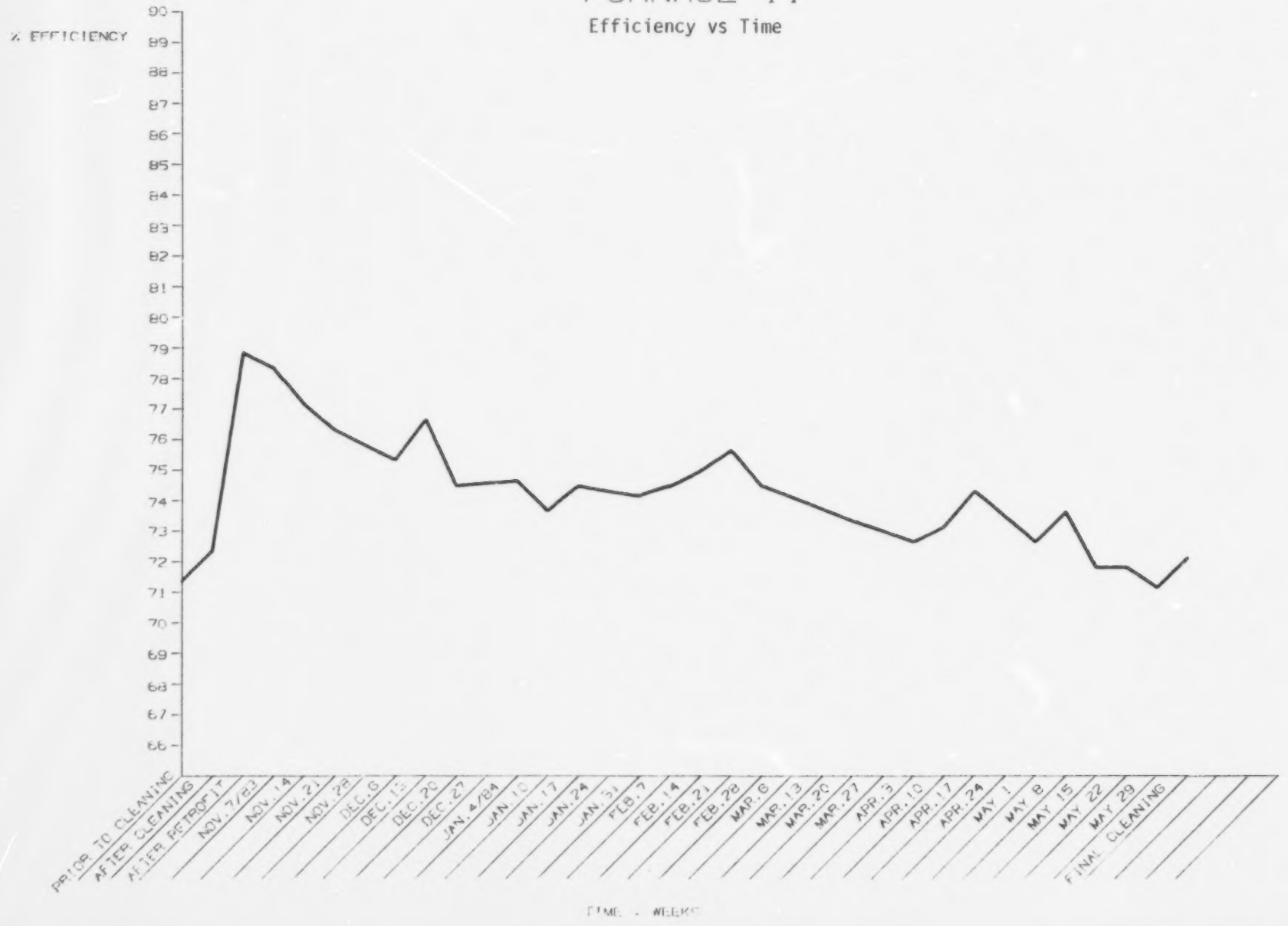


Figure B-3

FURNACE III

Efficiency vs Time

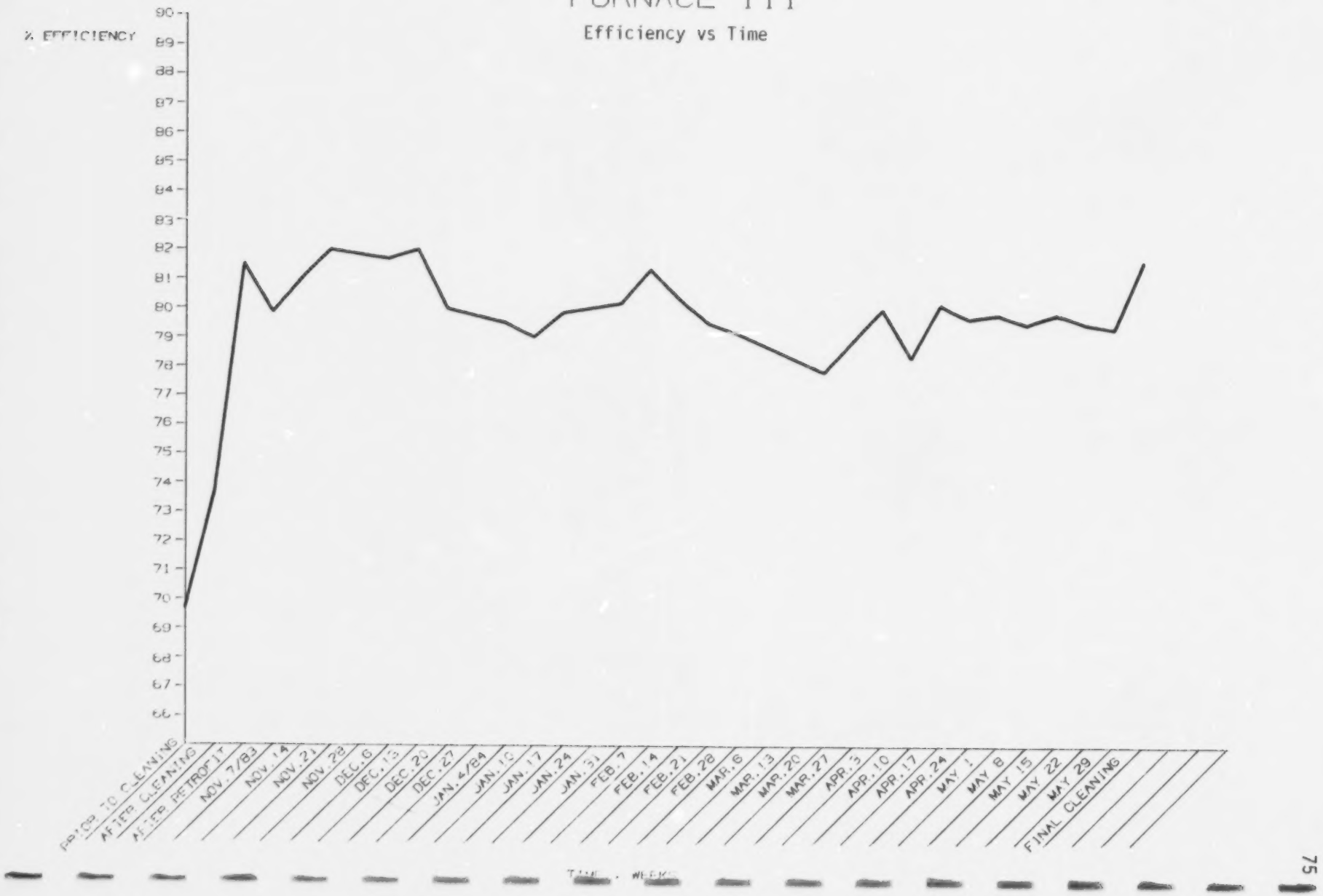
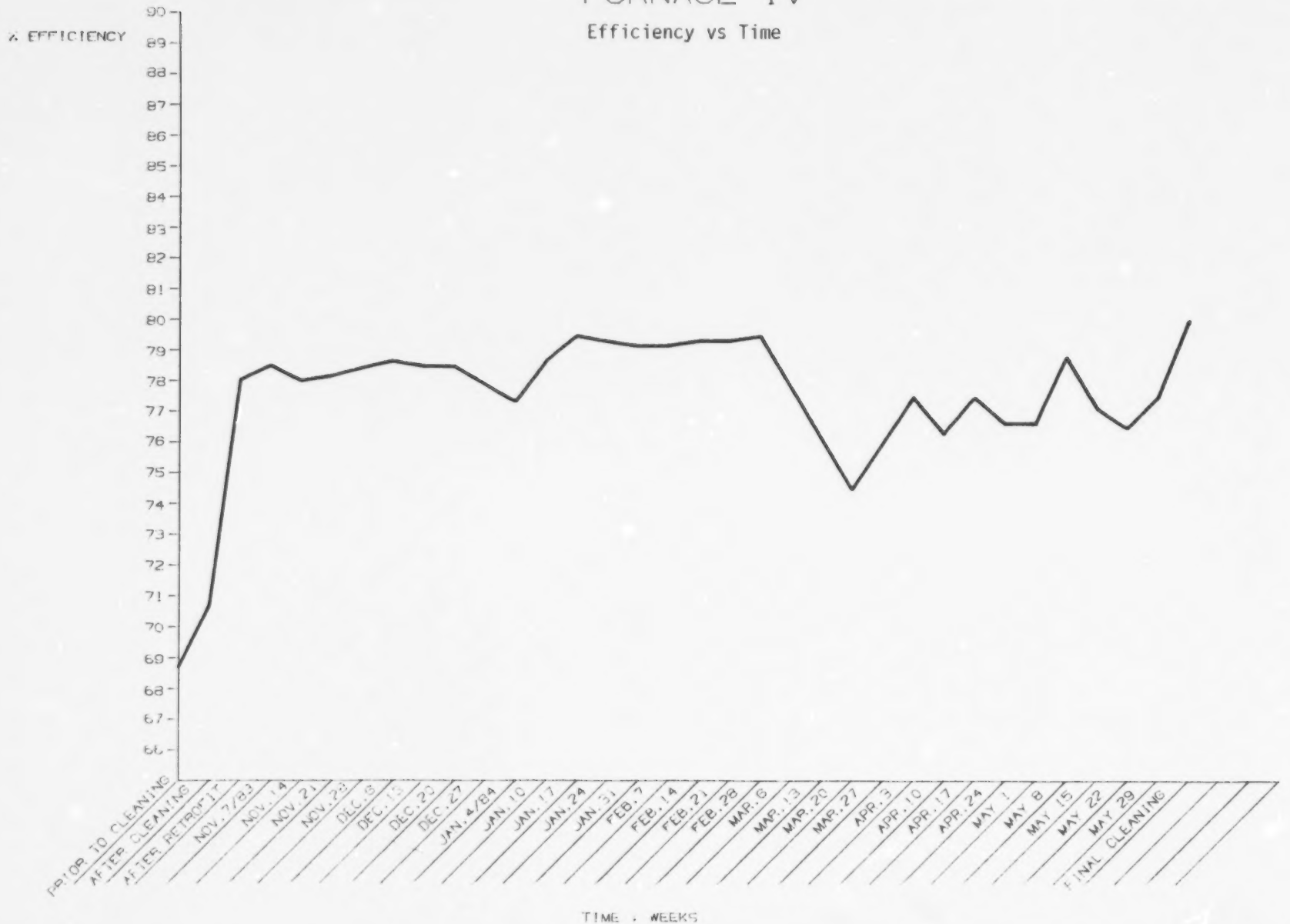


Figure B-4

FURNACE IV

Efficiency vs Time



APPENDIX C

WOOD RESIDUE TEST PROGRAM: BACKGROUND DATA

TABLE C-1: Wood Residues

Residue	Moisture Content (%) (wet basis) - Initial	Calorific Value (Btu/lb) As Received	100% Dry
Douglas Fir chip	13.2	7256	8359
Mixed softwood chip (Short)	11.4	7439	8396
Shavings	28.7	5970	8373
Sawdust 1	37.8	5252	8443
Sawdust 2	10.9	7419	8327
Bark	39.9	5000	8319
Energex pellets	8.5	7812	8938
Goodine chip	19.7	6688	8329

TABLE C-2: Physical Dimensions of Fuel

Length (inches)-L	Goodine Chip wt(g)	% Total	Short Chip wt(g)	% Total	Douglas Fir Chip wt(g)	% Total
Coarse > 1¼"	18.5	14.5	1.5	0.8	2.3	1.3
1 < L < 1¼	3.9	3.1	0.4	0.2	2.6	1.4
3/4 < L < 1	18.0	14.1	16.0	8.1	3.0	1.6
½ < L < 3/4	12.0	9.4	45.8	23.3	155.9	85.3
¼ < L < ½	30.0	23.6	61.0	31.0	18.6	10.2
Fines < ¼	15.3	12.0	15.8	8.0	0.4	0.2
Knots	1.9	1.5	15.5	7.9	---	---
Bark & Dirt	25.3	19.9	26.7	13.6	---	---
Twigs & Needles	2.3	1.8	14.0	7.1	---	---
TOTAL	127.2	99.9	196.7	100.0	86.0	100.0

Length (inches)-L	Shavings wt(g)	% Total	Bark/Wood * Weight (g)		% of Total wt.	
Coarse > 1¼	0.6	0.7	57.5	19.6	25.9	8.8
1 < L < 1¼	1.4	1.6	17.1	---	7.7	---
3/4 < L < 1	2.2	2.6	12.5	7.6	5.6	3.4
½ < L < 3/4	6.4	7.4	13.7	14.5	6.2	6.5
¼ < L < ½	24.6	28.6	19.3	---	8.7	---
Fines < ¼"	50.8	59.1	36.3	16.2	16.3	7.3
Knots	---	---	---	---	---	---
Bark & Dirt	---	---	7.8		3.5	---
Twigs & Needles	---	---	---	---	---	---
TOTAL	86.0	100.0	164.2	57.9	73.9	26.0
			222.1		99.9	

Sample stayed on Top of these sieves	Sawdust 1 wt (g)	% Total	Sawdust 2 wt (g)	% Total
0.530	0.9	0.3	---	---
0.250	34.5	12.0	---	---
0.0937	182.0	63.1	107.7	32.9
<0.0937	71.2	24.7	219.9	67.1
TOTAL	288.6	100.1	327.6	100.0

	Energex Pellets
Diameter (mm)	6
Average Length (mm)	10-15
Weight (g/10 mm)	0.38

*The "bark" was comprised of bark and wood slivers i.e., 2 components.

TABLE C-3: Equipment List

Gas Analyzers

Beckman Model 755 Paramagnetic oxygen
Beckman Model 864-23 CO_2 Infrared
Beckman Model 864-X CO Infrared
Beckman Model 400 Hydrocarbon
Beckman Model 951A NO/NO_x
Teledyne Model 611 DAMC SO_2 Photometric

Data Logger

Kaye Digistrip - III, programmable microprocessor controlled

Computer

Hewlett-Packard HP-85 microcomputer

Thermocouples

Type K

Air Flow/Pressure

MP6K8 Digital Micronometer, Air Instrument Resources Ltd.
Air Velocity Meter, Model 1650, tsi

Weight Scales

Toledo: 2155 scale with Model 8132 indicator and 0-10 volt option

Figure C-1: Residue Photograph

Figure C-1: Residue Photograph

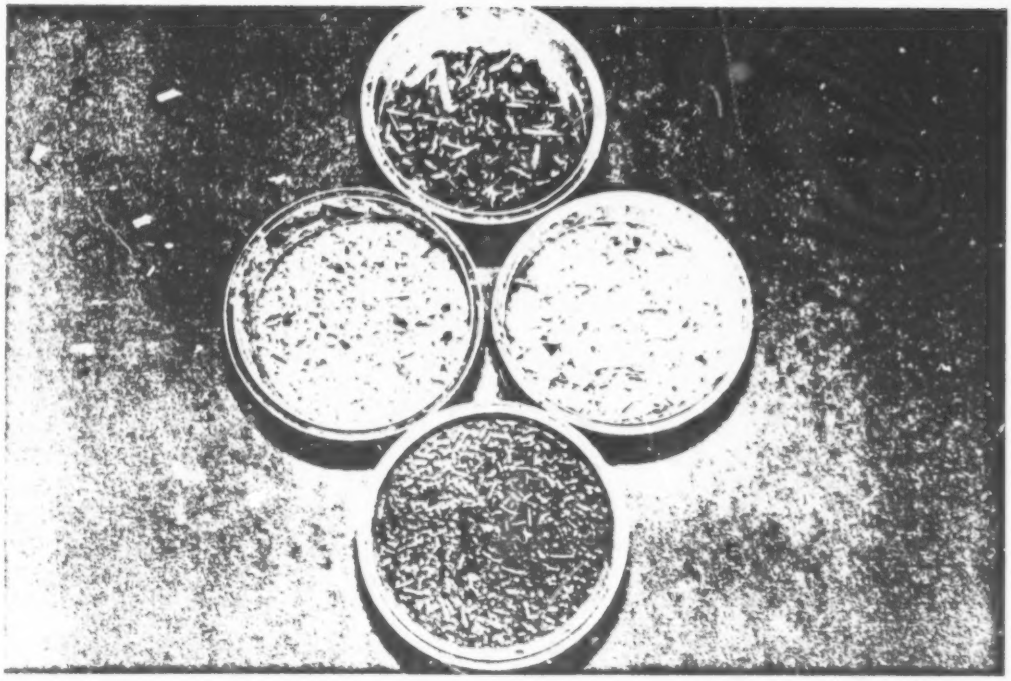
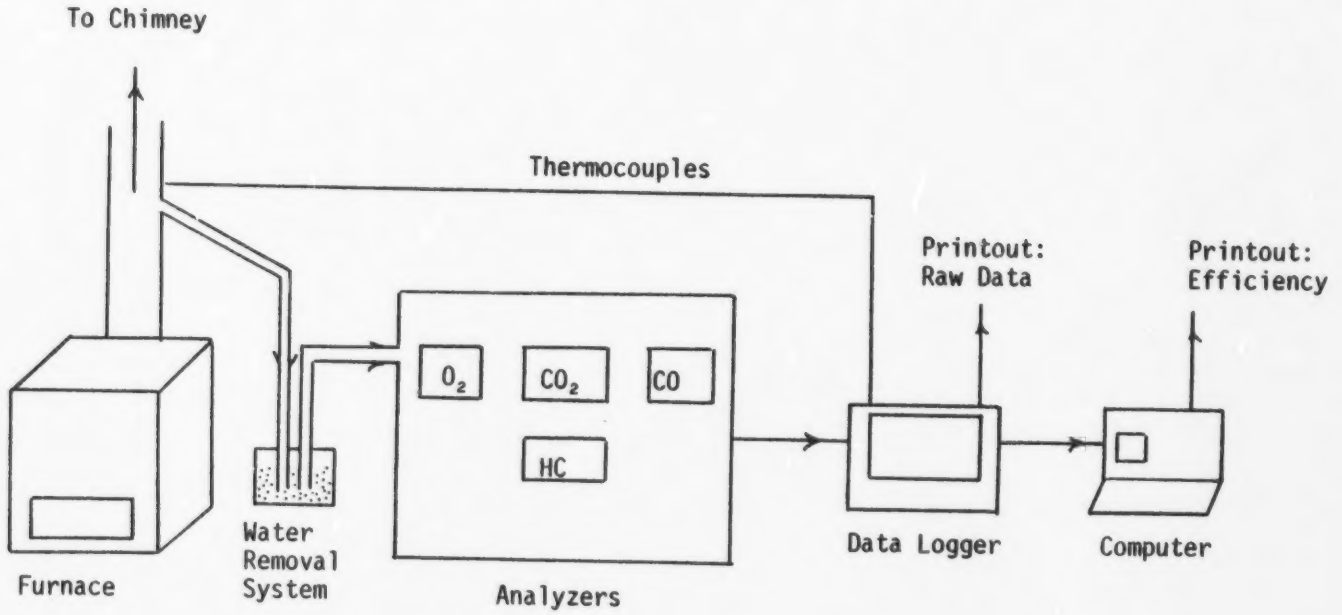


Figure C-2

Test Schematic



APPENDIX D

Gravity Fed Burner

TABLE D-1: Gravity Fed Burner Test Results

Test	1	2	3	4	5
Fuel Type	D.F.Chip	D.F.Chip	D.F.Chip	D.F.Chip	Sawdust 1
Moisture %	13.2	12.6	13.3	13.6	36.3
Calorific Value					
(Btu/lb) wet	7317	7368	7309	7284	5379
dry	8430	8430	8430	8430	8444
Wt. of Fuel Charge (Kg)	9.8	33.2	21.3	21.4	19.5
Energy in Fuel Charge(Btu)	157,755	538,159	342,500	344,108	230,759
Wt. of Ash Left (Kg)	0.129	0.255	0.316	0.230	0.0986
Calorific Value of Ash					
(Btu/lb)	12336	12503	13161	13026	7601
Energy in Ash (Btu)	3,501	7,014	9,150	6,591	1,649
Front Damper	auto	open	auto	auto	auto
Rear Damper	open	closed	closed	open	closed
Length of Burn (min)	65	160	125	120	65
Steady State Time (min)	20	45	65	65	25
Rate of Fuel Consumption					
(kg/hr)	20.7	27.6	13.9	13.9	41.8
Average Steady State: O_2%	2.5580	4.1158	6.8294	7.6956	6.2201
CO_2%	14.3784	13.968	13.105	11.155	9.746
CO%	0.2032	3.7777	1.2004	0.2993	10.5154
HC%	0.0146	0.4063	0.1884	0.0233	1.7681
Tstack °C	358.9	397.3	264.7	314.7	286.2
Efficiency %	78.4	67.8	81.5	80.8	49.0
Output (Btu/hr)	301,000	347,000	209,000	209,000	380,000

Comments: Fuel consumption was during steady state period.

Test	6	7	8	9	10
Fuel Type	Sawdust1	Sawdust1	ShortChip	ShortChip	Pellet
Moisture %	39.4	39.4	11.4	11.4	8.5
Calorific Value					
(Btu/hr) wet	5117	5117	7439	7439	7812
dry	8444	8444	8396	8396	8538
Wt. of Fuel Charge (kg)	19.8	19.5	19.8	19.8	11.2
Energy in Fuel (Btu)	222,897	219,519	324,043	365,730	192,488
Wt. of Ash Left (kg)	0.0351	0.1075	0.5154	0.2717	0.2697
Calorific Value of Ash					
Btu/lb	4028	*	4894	2317	3355
Energy in Ash (Btu)	311	1,375	5,549	1.385	1,991
Front Damper	auto	auto	auto	auto	auto
Rear Damper	closed	open	open	closed	open
Length of Burn (min)	115	75	100	135	100
Steady State Time (min)	25	25	30	40	40
Rate of Fuel Consumption					
(lb/hr)	74.9	61.7	38.2	46.8	31.1
Average Steady State: O_2%	6.4073	3.4108	6.0287	9.1109	13.1674
CO_2%	9.2572	12.0732	11.9886	8.1044	5.8778
CO%	10.4437	9.4197	3.7936	7.5975	1.120
HC%	1.7874	1.3187	0.5645	1.4517	0.21814
Tstack °C	196.5	301.7	331.0	293.7	287.3
Efficiency %	49.0	51.1	70.2	51.4	68.6
Output (Btu/hr)	310,000	266,000	225,000	201,000	182,000

Comments: 7 : CV ash: sample lost - estimate from 5 and 6, i.e.
(7601 + 40281)/2 = 5815

Test	11	12	13	14	15
Fuel Type	Pellet	Shavings	Bark	DF/Saw 1 2:1	DF/Saw 1 1:1
Moisture %	8.5	28.7	39.9	16.6	22.3
Calorific Value (Btu/hr) wet	7812	5970	5000	6912	6255
dry	8538	8373	8319	8228	8050
Wt. of Fuel Charge (kg)	9.9	12.0	12.0	11.2	11.2
Energy in Fuel (Btu)	170,145	--	--	170,312	154,123
Wt. of Ash Left (kg)	0.3373	--	--	0.1590	0.2506
Calorific Value of Ash Btu/lb	4410	--	--	12269	11847
Energy in Ash (Btu)	3,272	--	--	4,292	6,531
Front Damper	auto	auto	auto	auto	auto
Rear Damper	closed	closed	closed	open	open
Length of Burn (min)	105	failed	failed	60	50
Steady State Time (min)	35	--	--	20	20
Rate of Fuel Consumption (lb/hr)	24.2	--	--	54.9	54.9
Average Steady State: O_2%	5.2320	--	--	5.206	5.8431
CO_2%	12.4408	--	--	11.932	11.8690
CO%	2.3294	--	--	7.2476	3.209
HC%	0.6441	--	--	0.8672	0.794
Tstack °C	254.7	--	--	333.5	346.7
Efficiency %	74.7	--	--	56.5	61.6
Output (Btu/hr)	154,000	--	--	255,000	295,000

Comments: 12) would not feed - too light/fluffy

13) poor feed, would not burn

	Test 16	17	18	19	20
	DF/Saw	DF/Saw	DF/Saw	Saw2/Shav	Saw2/Shav
Fuel Type	1:2	2:1	1:1	1:1	2:1
Moisture %	24.6	14.9	16.4	14.7	13.9
Calorific Value					
(Btu/hr) wet	6181	7020	7020	7128	7220
dry	8198	8249	8397	8356	8386
Wt. of Fuel Charge (kg)	10.9	10.7	11.4	11.4	11.1
Energy in Fuel (Btu)	148,220	165,251	176,062	178,770	176,312
Wt. of Ash Left (kg)	0.1995	0.1375	0.0851	0.1685	0.0803
Calorific Value of Ash					
Btu/lb	11882	12145	9986	8411	4577
Energy in Ash (Btu)	5,215	3,674	1,870	3,118	809
Front Damper	auto	auto	auto	auto	auto
Rear Damper	open	open	open	open	open
Length of Burn (min)	50	80	75	80	80
Steady State Time (min)	10	30	25	30	25
Rate of Fuel Consumption					
(lb/hr)	72.6	36.0	40.1	33.8	48.5
Average Steady State: O_2%	4.274	3.2915	16.35	76036	6.5902
CO_2%	12.013	12.80		12.3598	11.5598
CO%	9.5174	0.1761	0.0349	0.1021	1.4809
HC%	2.2787	0.0437	0.00408	0.029	0.4473
Tstack °C	323.6	338.2	351.7	360.1	344.5
Efficiency %	47.5	79.4	84.0	79.0	69.3
Output (Btu/hr)	283,000	236,000	283,000	236,000	282,000

Test	21	22	23
	Saw2/Bark	Saw2/Bark	Saw2/Bark
Fuel Type	2:1	1:1	1:2
Moisture %	14.7	15.9	16.6
Calorific Value			
(Btu/hr) wet	7156	7066	7086
dry	8389	8402	8496
Wt. of Fuel Charge (kg)	11.2	11.1	11.5
Energy in Fuel (Btu)	176,324	172,552	179,276
Wt. of Ash Left (kg)	0.1282	0.1430	0.1749
Calorific Value of Ash			
Btu/lb	1122	4245	2516
Energy in Ash (Btu)	316	1,335	968
Front Damper	auto	auto	auto
Rear Damper	open	open	open
Length of Burn (min)	85	95	145
Steady State Time (min)	40	50	65
Rate of Fuel Consumption			
(lb/hr)	30.3	24.2	11.8
Average Steady State: O_2%	8.46	8.807	15.7
CO_2%	10.24	10.651	4.24
CO%	4.009	0.4636	0.1361
HC%	0.5098	0.1064	0.01266
Tstack °C	293.0	290.0	208.0
Efficiency %	63.3	80.3	71.7
Output (Btu/hr)	159,000	164,000	72,000

TABLE D-2

Moisture vs. Efficiency

% Moisture	No. of Tests	% Efficiency
8.5	2	71.7
12.6	6	71.7
15.5	8	72.9
23.5	2	54.6
38.4	3	49.7

TABLE D-3

Moisture vs. CO/HC Emissions

Residue Type	No. of Tests Involved	% Moisture	Average % CO	% HC
Pellet	2	8.5	1.72	0.43
Douglas Fir Chip	4	9.8	1.37	0.16
Short	2	11.4	5.70	1.01
Sawdust 1	3	38.4	10.13	1.62

Figure D-1

Efficiency vs Moisture
Gravity-fed Burner

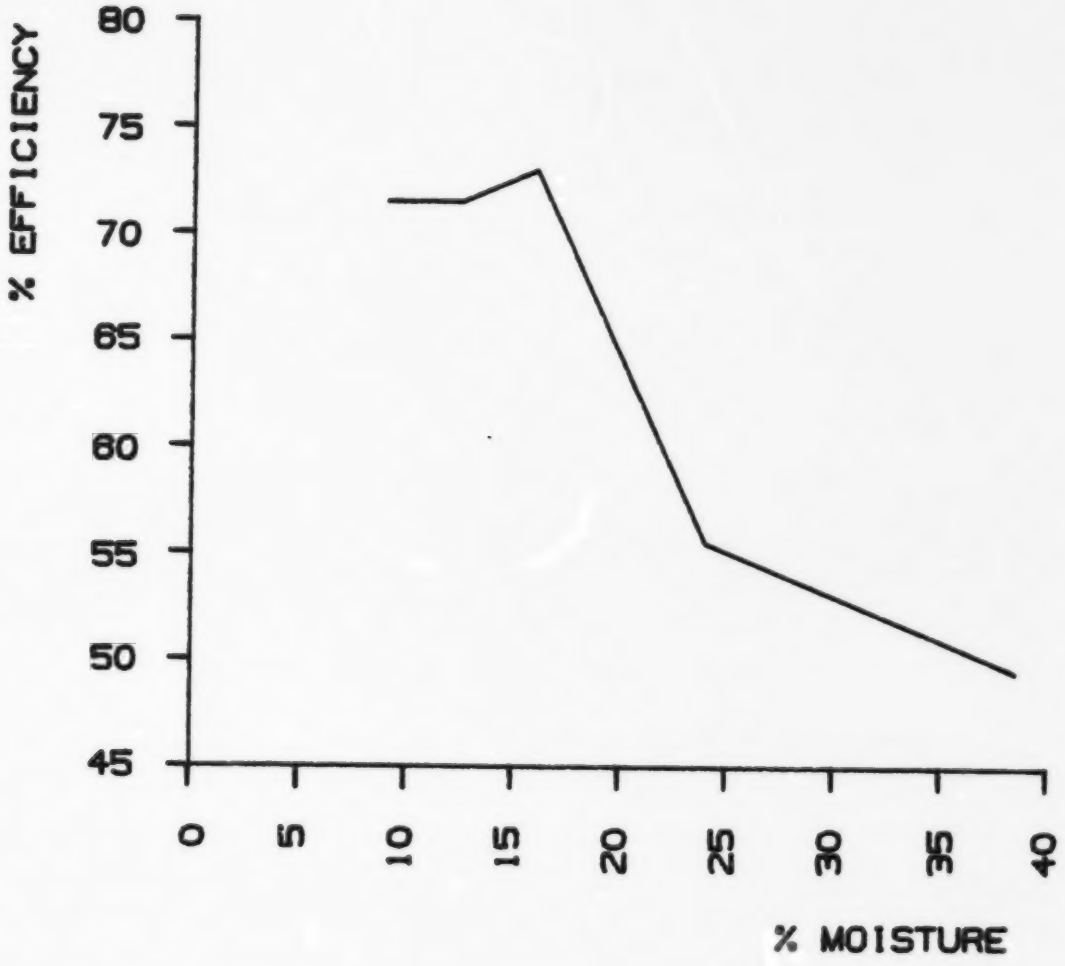
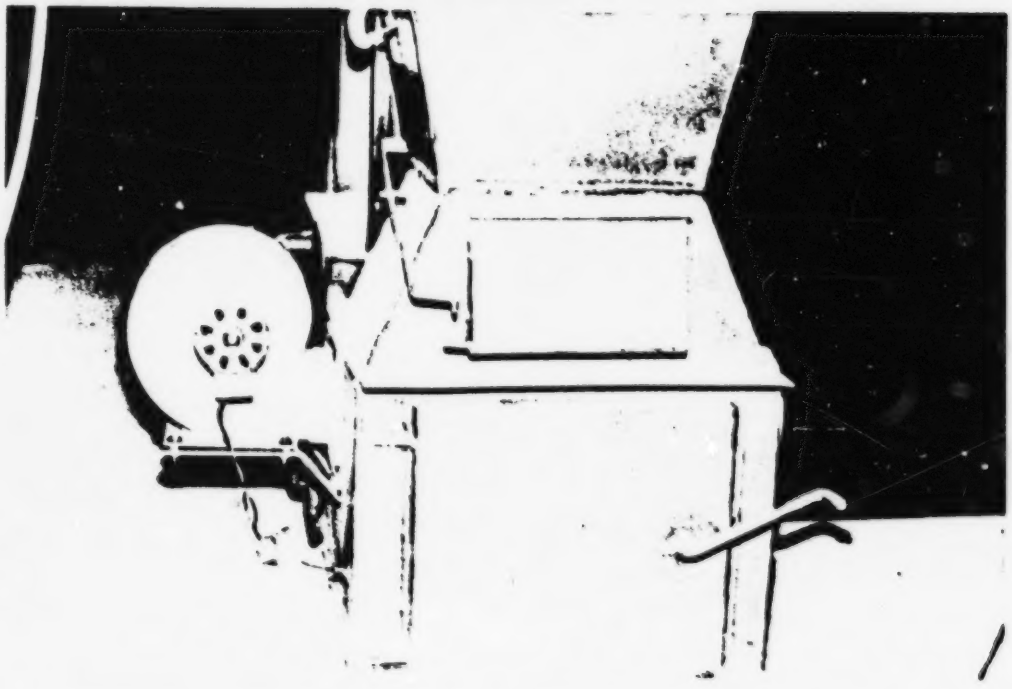


Figure D-2



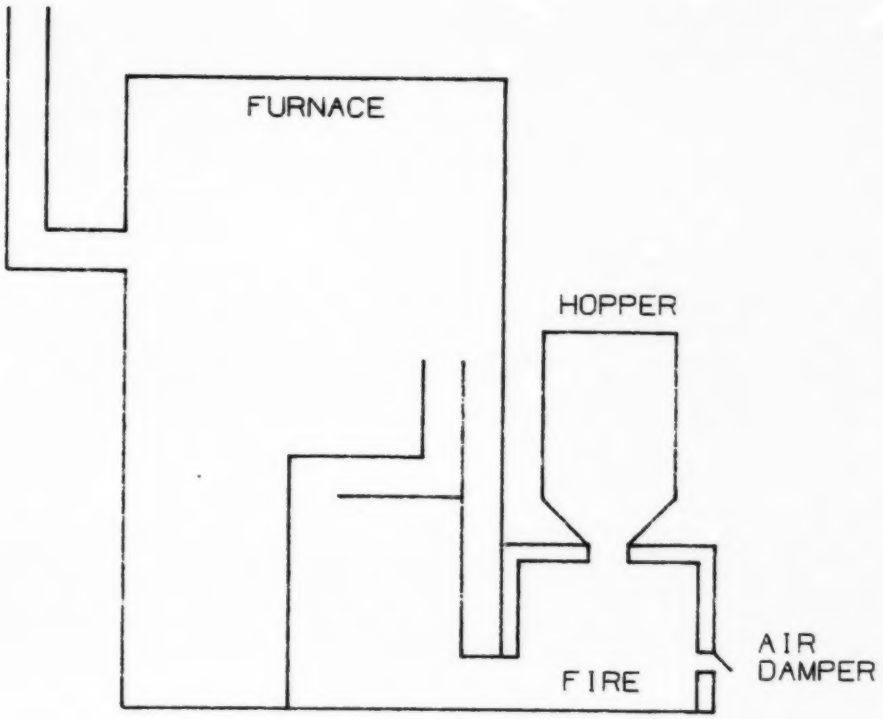
Photograph of Gravity Fed Residue Combustor. Foreground: Burner Assembly with air damper and hopper. Background: Wood Furnace.

Figure D-2

Photograph of Gravity Fed Residue Combustor. Foreground: Burner Assembly with air damper and hopper. Background: Wood Furnace.

Figure D-3

SCHEMATIC DIAGRAM OF
GRAVITY FED STOKER SYSTEM



APPENDIX E

Auger Fed Stoker

TABLE E-1: Auger Fed Stoker Test Results

	Test 1	2	3	4	5
Fuel Type	DouglasFir chip	Goodine chip	Short chip	Pellets	Shavings
Moisture %	11.8	19.7	11.4	8.5	28.7
Calorific Value (Btu/hr) wet	7400	6688	7439	7812	--
dry	8390	8329	8396	8538	--
Wt. of Fuel Charge (kg)	11.5	10.8	11.6	--	--
Energy in Fuel (Btu)	187,220	158,907	189,843	--	--
Wt. of Ash Left (kg)	0.2143	0.2802	0.2926	--	--
Calorific Value of Ash Btu/lb	10876	8338	10,000	--	--
Energy in Ash (Btu)	5,125	5,140	6,437		
UFCA	open	open	open	--	--
OFCA	open	open	open	--	--
Length of Burn (min)	110	120	105	Failed	Failed
Steady State Time (min)	65	65	60	--	--
Rate of Fuel Consumption (kg/hr)*	7.7	6.1	8.6	--	--
Average Steady State: O_2%	13.32	14.10	11.85	--	--
CO_2%	7.14	5.30	8.55	--	--
CO%	0.0266	0.1021	0.0389	--	--
HC%	0.0021	0.0007	0.0000	--	--
Tstack °C	286.8	264.0	317.4	--	--
Efficiency %	75.1	70.1	75.0	--	--
Output (Btu/hr)	107,000	78,000	119,000	--	--

Comments: (3) C.V. of ash is a guess - sample lost.

(4) Feed rate too fast - unburned pellets spilling from bowl.

(5) Feed too slow-fuel consumed immediately - burn back started.

* During steady state period.

	Test 6	7	8	9	10
Fuel Type	Bark	Sawdust 2	DF/Shavings 2:1	DF/Bark 2:1	DF/Bark 1:1
Moisture %	10.8	8.8	--	11.5	12.8
Calorific Value					
(Btu/hr) wet	7649	7619	--	7480	7456
dry	8576	8355	--	8452	8550
Wt. of Fuel Charge (kg)	4.8	10.8	--	8.1	7.5
Energy in Fuel (Btu)	80,773	181,027	--	133,294	123,024
Wt. of Ash Left (kg)	0.1331	0.2213	--	0.1414	0.130
Calorific Value of Ash					
Btu/lb	1768	8942	--	8862	7730
Energy in Ash (Btu)	518	4,354	--	2,757	2,211
UFCA	open	open	--	open	open
OFCA	open	open	--	open	open
Length of Burn (min)	95	100	Failed		110
Steady State Time (min)	55	70	--		85
Rate of Fuel Consumption					
(kg/hr)*	3.7	8.1	--	7.1	4.8
Average Steady State: O_2%	17.245	12.195	--	14.38	16.17
CO_2%	3.232	7.6724	--	4.58	4.33
CO%	0.1150	0.2374	--	0.04354	0.0979
HC%	0.0128	0.0101	--	0.0007	0.0094
Tstack °C	182.8	273.8	--		205.5
Efficiency %	69.6	77.2	--	65.4	71.9
Output (Btu/hr)	48,000	115,000	--	86,000	65,000

Comments: * Steady state

Test	11	12	13	14	15
Fuel Type	DF/Bark 1:2	DF/Saw 2 1:1	Saw 2/Bark 1:1	DF Chip	DF Chip
Moisture %	11.1	10.3	9.8	11.8	11.8
Calorific Value (Btu/hr) wet	7569	7511	7636	7400	7400
dry	8514	8373	8466	8390	8390
Wt. of Fuel Charge (kg)	5.4	8.0	5.3	5.5	5.6
Energy in Fuel (Btu)	89,920	132,194	89,036	89,540	91,168
Wt. of Ash Left (kg)	0.1178	0.2104	0.062	0.0918	0.0740
Calorific Value of Ash Btu/lb	7408	11827	3212	12848	13356
Energy in Ash (Btu)	1,920	2,488	438	2,595	2,174
UFCA	open	open	open	open	closed
OFCA	open	open	open	open	open
Length of Burn (min)	80	70	65	60	60
Steady State Time (min)	55	40	35	30	30
Rate of Fuel Consumption (kg/hr)*	4.8	10.0	5.9	7.8	7.8
Average Steady State: O_2%	16.07	10.41	14.71	11.144	11.757
CO_2%	4.51	9.55	5.70	9.002	8.8501
CO%	0.0920	0.0379	0.1394	0.0385	0.0288
HC%	0.0109	0.00346	0.0075	0.0007	0.00009
Tstack °C	205.9	312.0	237.2	268.8	281.8
Efficiency %	72.4	78.8	74.5	81.2	78.2
Output (Btu/hr)	65,000	145,000	81,000	117,000	113,000

Comments: * Steady state

	Test 16	17	18	19	20
Fuel Type	DF Chip	Shavings	DF/Pellet 2:1	DF/Pellet 1:1	DF Chip
Moisture %	11.8	--	10.7	10.2	11.8
Calorific Value (Btu/hr) wet	7400	--	7536	7601	7400
dry	8390	--	8439	8464	8390
Wt. of Fuel Charge (kg)	5.6	--	8.2		9.0
Energy in Fuel (Btu)	91,168	--	135,949		146,520
Wt. of Ash Left (kg)	0.1891	--	0.1082	0.0314	0.1943
Calorific Value of Ash Btu/lb	13007	--	10330	6655	12643
Energy in Ash (Btu)	5,411	--	2,459	460	5,404
UFCA	closed	--	open	open	½ open
OFCA	closed	--	open	open	½ open
Length of Burn (min)	60	failed	80	70	80
Steady State Time (min)	30	--	35	15	50
Rate of Fuel Consumption (kg/hr)*	8.2	--	9.0	13.6	8.0
Average Steady State: O_2%	10.069	--	10.009	4.0999	11.451
CO_2%	10.740	--	10.2829	14.3905	8.315
CO%	0.0796	--	0.0284	0.2086	0.0299
HC%	0.0039	--	0.0	0.013	0.00172
Tstack °C	269.0	--	345.8	389.9	285.0
Efficiency %	84.3	--	79.6	79.0	78.5
Output (Btu/hr)	128,000	--	132,000	200,000	115,000

Test	21	22	23	24	25
Fuel Type	DF Chip	DF Chip	DF Chip	DF Chip	DF Chip
Moisture %	11.8	11.8	11.8	11.8	11.8
Calorific Value					
(Btu/hr) wet	7400	7400	7400	7400	7400
dry	8390	8390	8390	8390	8390
Wt. of Fuel Charge (kg)	8.8	8.8	8.8		
Energy in Fuel (Btu)	143,264	143,264	143,264		
Wt. of Ash Left (kg)	0.1553	0.1367	0.2490	0.2614	0.1517
Calorific Value of Ash					
Btu/lb	12824	13159	13803	12916	13131
Energy in Ash (Btu)	438	3,957	7,561	7,428	4,382
UFCA	½ open	open	½	½ open	open
OFCA	open	½ open	½	½ open	½ open
Length of Burn (min)	85	80	80	80	140
Steady State Time (min)	50	35	40	50	40
Rate of Fuel Consumption					
(kg/hr)	8.0	7.6	8.4	8.3	7.9
Average Steady State: O_2%	12.497	12.654	10.443	10.334	11.729
CO_2%	7.7381	7.073	8.620	8.398	8.214
CO%	0.014	0.0493	0.0793	0.0742	0.0201
HC%	0.0004	0	0.0002	0.0006	0.0010
Tstack °C	287.2	283.4	271.7	269.1	271.9
Efficiency %	77.3	74.9	80.3	79.5	79.5
Output (Btu/hr)	113,000	105,000	124,000	122,000	116,000

	Test 26	27
Fuel Type	DF Chip	DF Chip
Moisture %	36.6	24.3
Calorific Value (Btu/hr) wet	5319	6351
dry	8390	8390
Wt. of Fuel Charge (kg)	8.8	8.8
Energy in Fuel (Btu)	102,976	122,955
Wt. of Ash Left (kg)	0.2013	0.1967
Calorific Value of Ash Btu/lb	12836	12947
Energy in Ash (Btu)	5,685	5,603
UFCA	open	open
OFCA	open	open
Length of Burn (min)	90	90
Steady State Time (min)	40	40
Rate of Fuel Consumption (kg/hr)	7.8	7.8
Average Steady State: O_2%	6.93	8.20
CO_2%	12.02	10.34
CO%	6.3919	2.4935
HC%	1.7519	0.4763
Tstack °C	245.0	267.4
Efficiency %	55.0	68.9
Output (Btu/hr)	74,000	92,000

Notes:

D.F. chips were soaked in water and then set out on plastic sheets. #26 was the 1st sample taken. Sample 2 (#27) was taken approximately 1½ - 2 wks later.

TABLE E-2

Combustion Air Settings vs. Efficiency

UFCA	OFCA	Average Efficiency (%)
Open	Open	78.2
Closed	Open	78.2
½	½	78.5
½	Open	77.3
Open	½	74.9
¼	¼	79.9
Open	¼	79.5
Closed	Closed	84.3

TABLE E-3

Efficiency/Output vs. Moisture Content

Douglas Fir Chip

Auger Fed System

Moisture Content %	# of Tests	Average % Efficiency	Heat Output (Btu/hr)
11.8	10	78.9	116,000
24.3	1	68.9	92,000
36.6	1	55.0	74,000

TABLE E-4

CO/HC Emissions vs. Moisture Content

Douglas Fir Chip

Moisture Content %	Average % CO	Average % HC
11.8	0.04	0.01
24.3	2.5	0.5
36.6	6.4	1.8

Figure E-1

Efficiency vs Moisture
Auger-fed Burner

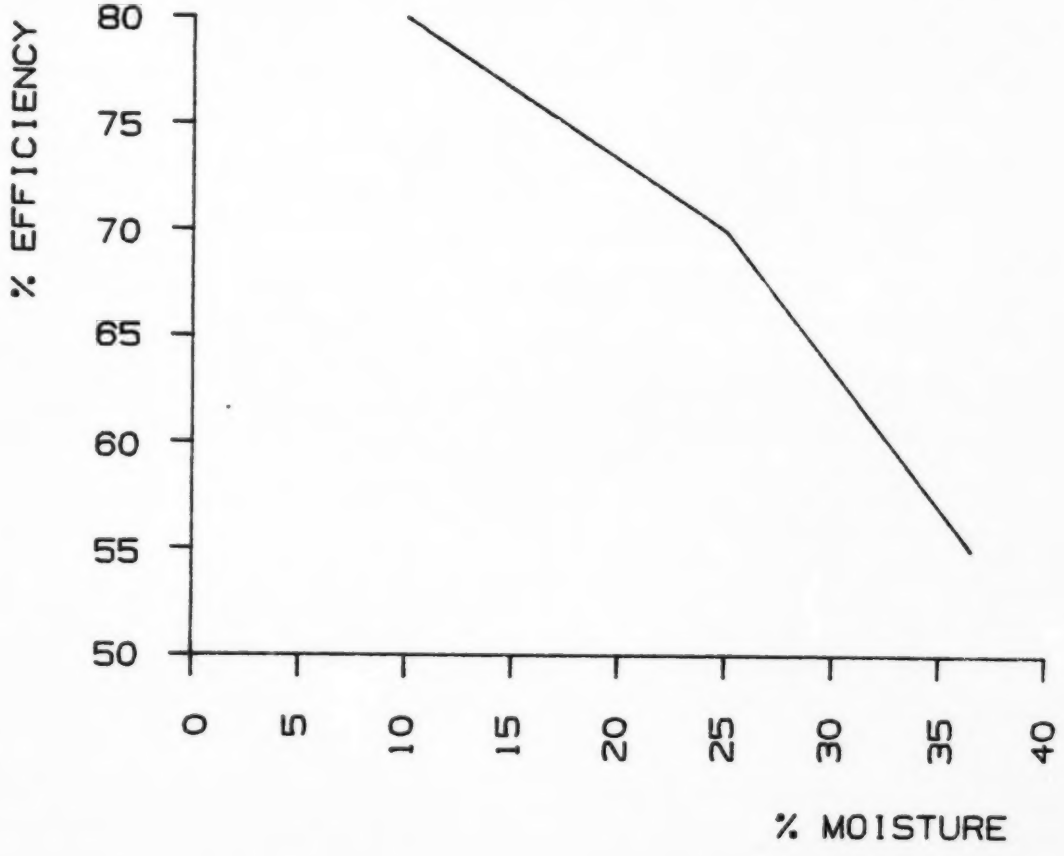


Figure E-2

SCHEMATIC DIAGRAM OF AUGER FED STOKER SYSTEM

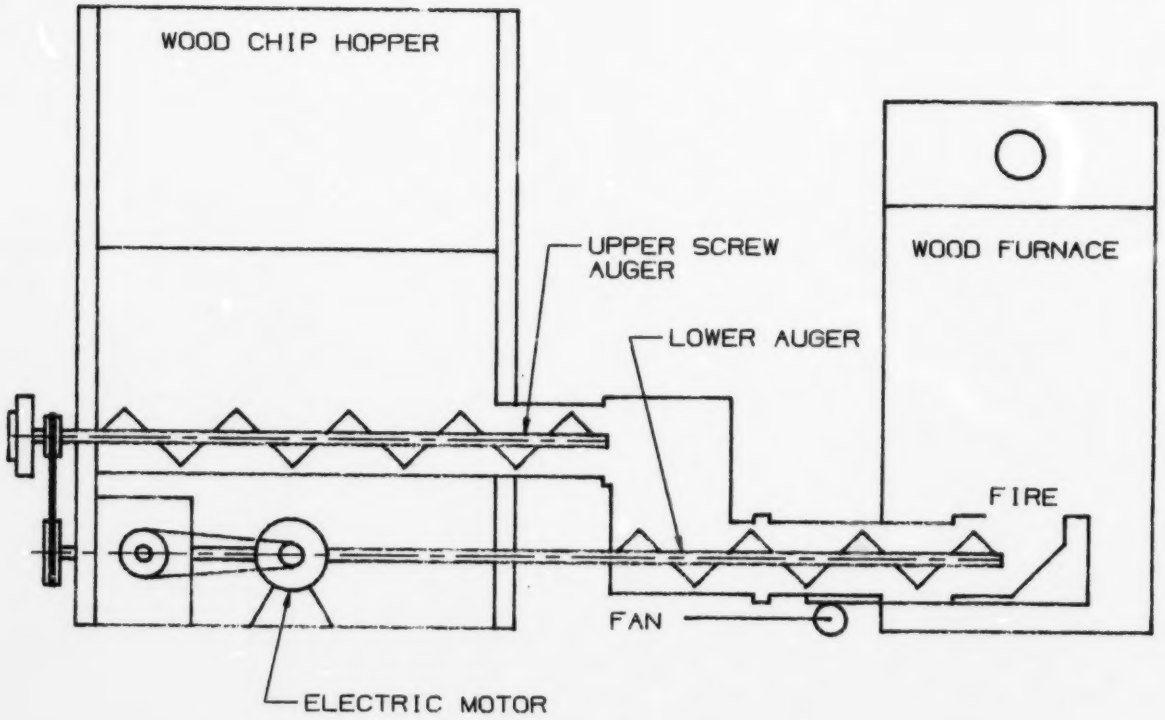
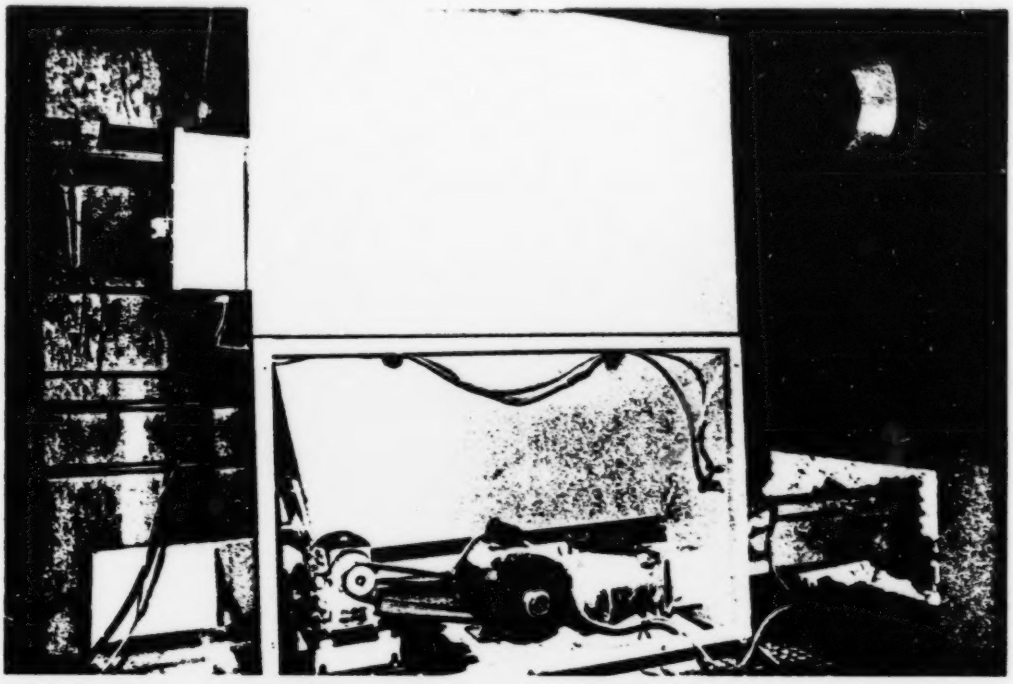
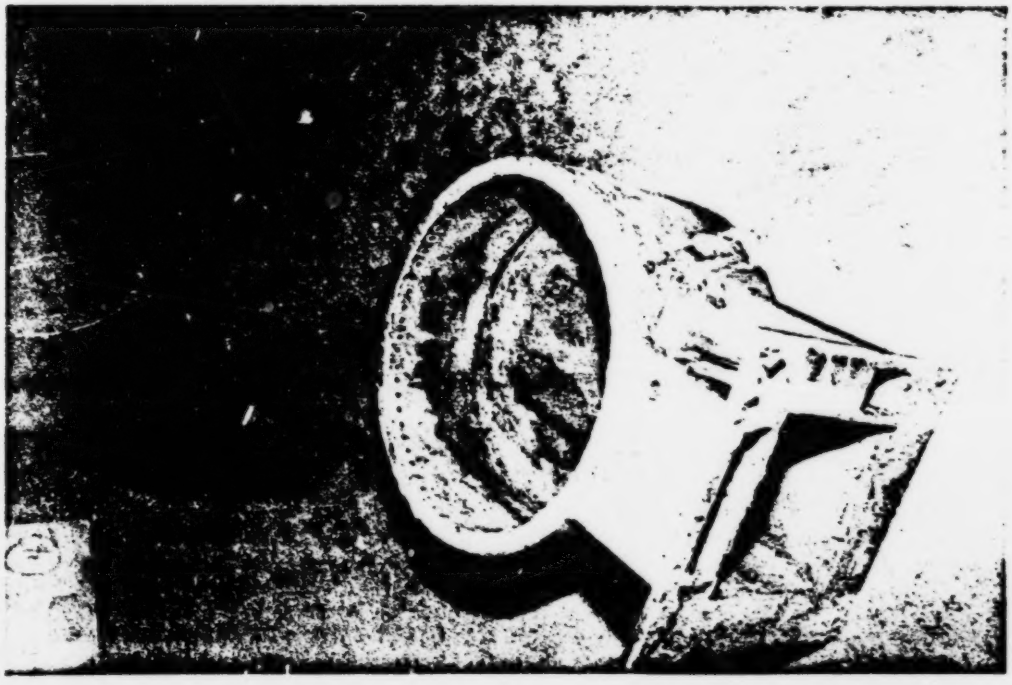


Figure E-3



Photograph of automatic stoker unit (left) and wood fired furnace.



Combustion bowl located inside furnace.

Figure E-3

Photograph of automatic stoker unit (left) and wood fired furnace.

Combustion bowl located inside furnace.

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